Streamlining C++ Programs

Price $4.50 U.S.
(Canada $5.95)

The C Users Jo al™

ID IC4
Lichtman's
$ 5.95

March 1994 12, Number 3

Advanced Solutions for C/C++ Programmers

Real-Time/ Embedded Systems

- Fuzzy Logic Replaces a PID Loop
- Symbolic Control for Embedded Systems
- Embedding an EXE File

Also:

- Making OOP More Efficient
- Adding Prediction to the Korn Shell
- Book Review: C Elements of Style

Columns By:

P.J. Plauger
Ken Pugh
Dan Saks
Victor R. Volkman
Chuck Allison

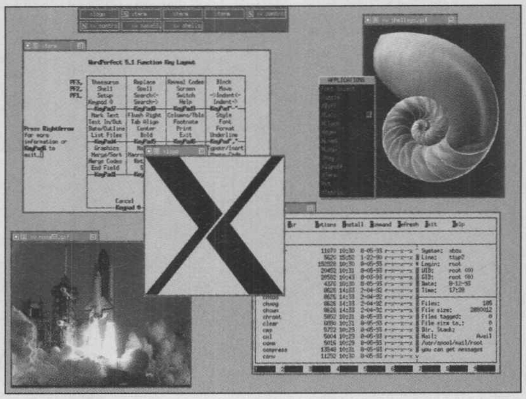
03
0 38808 74098 9

Can't Wait To See In UNIX.

Do Windows Without Getting Soaked!

It's an eyeopener! The multi-user, multi-tasking power of UNIX in Coherent with X-Windows. It's the GUI everyone's looking for. Multiple overlapping windows. Graphic color. And the price? You won't believe your eyes!

But Coherent was independently developed by Mark Williams Company as a virtual clone of UNIX. So it comes with a very un-UNIX-like price.



Software Critics And Over 60,000 Users Say it All!

Coherent has been hailed as possibly the best thing that ever happened to UNIX. And with tens of thousands of users, the critics are still marveling.

> "For price/performance, Coherent beats every other 32-bit operating system in the business."
> –Steven J. Vaughan-Nichols, *Computer Shopper*

> "To paraphrase Annie Oakley, 'Anything U(NIX) can do, Coherent can do better.'"
> –Michele Petrovsky, *LAN Computing*

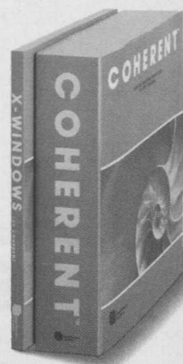
Coherent With X-Windows

Run The World's Best Selling Software!

Coherent now runs WordPerfect, Lotus 1-2-3 and most every other UNIX PC application right out of the box. Call for current information. Whatever the software, chances are Coherent runs it now!

$149.95

(Without X-Windows, $99.95)



You Simply Can't Go Wrong.

Mark Williams Company has been developing professional programming products since 1976. Our free unlimited technical support along with our popular BBS are renowned. We ship most orders within 24 hours, which means you'll have the power of Coherent in your hands in no time. And with our extended money-back guarantee, you can't miss.

So pick up the phone and order Coherent 4.2 with X-Windows today. And get everything you can't wait to see.

Small Is Beautiful In So Many Ways.

Coherent embraces the original UNIX philosophy: Small is beautiful. Small price, obviously. But Coherent has other size advantages as well.

Its 5-disk installation is a breeze. Just plug and play. No need for CD-ROM drives or special device adapters. And Coherent can reside with DOS so you can keep all your DOS windows applications, too.

Don't Let The Price Fool You

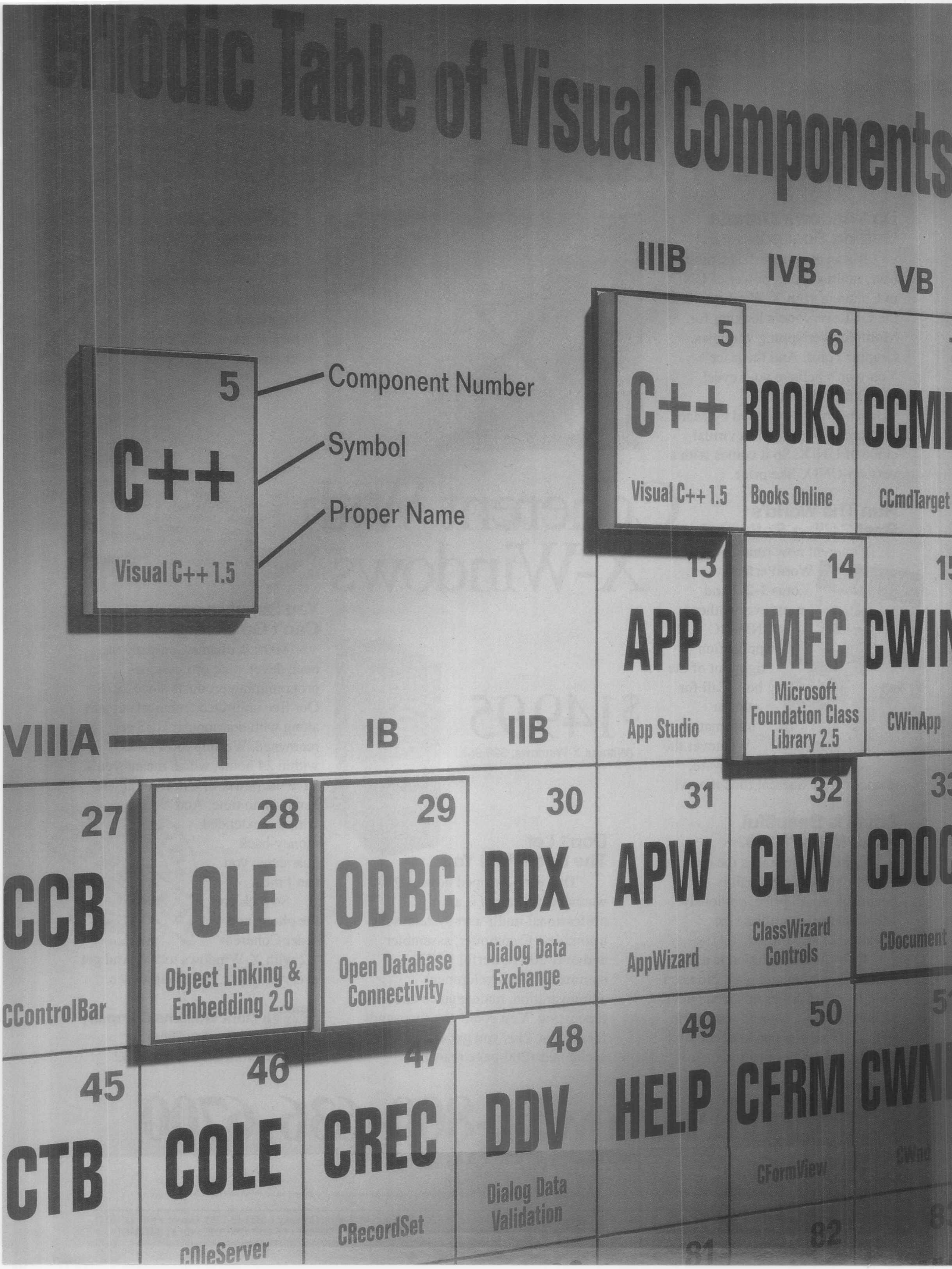
This is no stripped down UNIX wannabe. Coherent is a fully professional multi-user system with a complete C compiler, assembler and over 200 powerful UNIX commands for development, administration, maintenance and text processing. You could pay thousands for all this. Plus you get our acclaimed 1200-page manual.

Mark Williams Company
60 Revere Drive
Northbrook, IL 60062

Order Now! 1-800-636-6700

or 708-291-6700, FAX: 708-291-6750

Distributors: Australia + 07-266-2270, Brazil + 011-883-2299, Czech. + 06-32-62877, France +1-4741-4519, + 1-4672-8074, Germany + 0511-53-7295, Greece + (01) 222-3511, Holland + 2240-18499, Hungary + 153-0988, Malaysia + 03-756-4477, Venezuela/Caribbean + 1-809-723-5000, Sweden + 06-60-19290, UK + (0) 81-541-5466



riodic Table of Visual Components
5
C++
Visual C++ 1.5
Component Number
Symbol
Proper Name
IIIB
IVB
VB
5
C++
Visual C++ 1.5
6
BOOKS
Books Online
CCMD
CCmdTarget
13
APP
App Studio
14
MFC
Microsoft Foundation Class Library 2.5
15
CWIN
CWinApp
VIIIA
IB
IIB
27
CCB
CControlBar
28
OLE
Object Linking & Embedding 2.0
29
ODBC
Open Database Connectivity
30
DDX
Dialog Data Exchange
31
APW
AppWizard
32
CLW
ClassWizard Controls
33
CDOC
CDocument
45
CTB
46
COLE
COleServer
47
CREC
CRecordSet
48
DDV
Dialog Data Validation
49
HELP
50
CFRM
CFormView
CWND
CWnd
82

THE BUILDING BLOCKS OF VISUAL DEVELOPMENT.

The elements of next generation applications are found in the components of the Microsoft® Visual C++™ development system, version 1.5 today.

Innovative *wizard* technology allows you to seamlessly meld components into sophisticated applications, in weeks not months. Just remember this simple equation: MFC 2.5, OLE 2.0, ODBC. That's a perfect formula for building and reusing components. At the nucleus is MFC 2.5 (Microsoft Foundation Class Libraries), the standard API for Windows.™ The new OLE (Object Linking and Embedding) classes make it easier than ever to implement OLE's unprecedented integration power, new drag-and-drop features, visual editing and OLE automation. In all, it provides more than 19,000 lines of code you want, but won't have to write or rewrite.

In addition, the new ODBC (Open Database Connectivity) classes provide access to major databases and data binding without coding. It's a powerful new platform for creating high-performance database applications.

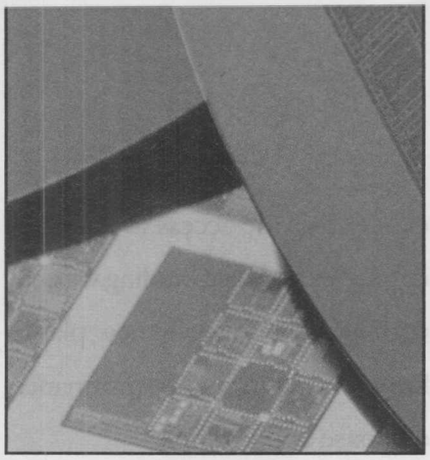
Best of all, your 16-bit MFC applications are portable to the Windows NT™ operating system and future versions of Windows. Now that's good chemistry.

If you want the latest tools for the latest Windows technology, ask for Microsoft Visual C++ 1.5.

Call us now at (800) 434-3980 and we'll make you a catalyst for change today and into the future of Windows operating systems.

New 16-bit version 1.5 joins the Visual C++ family of development systems for Windows and Windows NT.

Microsoft®



The C Users Journal™

Advanced Solutions for C/C++ Programmers

REAL-TIME/EMBEDDED SYSTEMS

FEATURES

BOOK REVIEW

Cover Photo by Steve Dunwell © 1987 Steve Dunwell/The Image Bank
The C Users Journal (ISSN 0898-9788) is published monthly by R&D Publications, Inc., 1601 W. 23rd St., Suite 200, Lawrence, KS 66046-2700 (913) 841-1631. Second-class postage paid at Lawrence, KS and additional mailing offices. POSTMASTER: Send address changes to THE C USERS JOURNAL, 1601 W. 23rd St., Suite 200, Lawrence, KS 66046-2700. **Subscriptions:** Annual renewable subscriptions to *The C Users Journal* are $29.95 US, $46 Canada and Mexico, $65 overseas. Payments must be made in US dollars. Make checks payable to *The C Users Journal.* **GST (Canada): #129065819**

COLUMNS

DEPARTMENTS

CUJ Online Source Code

You can obtain all code published (and some unpublished) in *CUJ* from:

USENET (Archived by UUNET Technologies):

uunet!~/published/cuj/19YY/monYY.tar.Z

Available via anonymous FTP from `ftp.uu.net` or via *uucp* from (900)GOT-SRCS.

Download via *uucp* and uncompress using `compress -d filename`, then `tar xvf filename` to expand the archive.

BBS:

CornerStone, 206-362-4283; The Courts of Chaos, 501-985-0059; EmmaSoft Shareware Board, 607-533-7072; Phoenix Chapter ACM Library, 602-970-0474; The Programmer's Corner, 301-596-7692; The Brass Cannon, 801-226-8310.

CompuServe:

In Library 7, CLMFORUM

GEnie:

In the IBM-PC Roundtable at page 615 (Keyword: IBMPC).

Monthly Code Disk:

Call R&D Publications, Customer Relations, (913) 841-1631.

The C Users Journal™

EDITORIAL

Publisher	*Robert Ward*
Senior Editor	*P. J. Plauger*
Managing Editor	*Marc Briand*
Contributing Editors	*Chuck Allison*
	Steve Graham
	Kenneth Pugh
	Dan Saks
	Victor R. Volkman
	Sydney Weinstein

CUSTOMER SERVICE

Customer Service	*Pam VanSchmus*
	Jodi Leonard
913-841-1631	*FAX 913-841-2624*

ADVERTISING AND MARKETING

Marketing Director	*Jeff Dickey-Chasins*
Acct. Manager, East	*Ed Day*
	913-841-1622
Acct. Manager, Midwest	*Christine Woodley*
	913-841-6733
Acct. Manager, West	*Edwin Rothrock*
	913-841-1626
European	*Brian Osborn*
Advertising	*Hohenleuchte 10 A*
Representative	*D-24159 Kiel*
	Germany
	+49 431-396895
	FAX +49 431-396827
Sales Services	*Danelia Quiroz*
Advertising Services	*Noelle M. Martin*
Direct Marketing	*Bill Uhler*

PRODUCTION

Art Director	*Susan Schuette Buchanan*
Graphic Artist	*Twyla Watson Bogaard*
Production Editor	*Liza Behymer*
Advertising Materials	*Lori White*

The C Users Journal is the successor to the *C Users' Group Newsletter* and *The C Journal*. Subscribers are automatically enrolled as members of The C Users' Group. *The C Users Journal* and The C Users' Group are services of R&D Publications, Inc., Lawrence, KS.

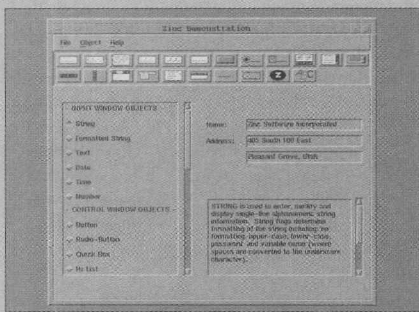
Printed in the United States of America.

The Audit Bureau

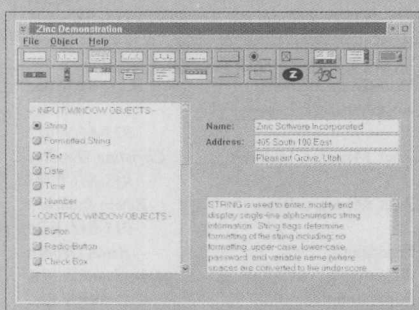
Advertising: For rate cards or other information on placing advertising in *The C Users Journal*, contact the advertising department at (913) 841-1631, or write *The C Users Journal*, 1601 W. 23rd St., Ste. 200, Lawrence, KS 66046-2700.
Customer Service: For subscription orders and address changes, contact *The C Users Journal*, 1601 W. 23rd St., Ste. 200, Lawrence, KS 66046-2700. Telephone (913) 841-1631; FAX (913) 841-2624; e-mail `cujsub@rdpub.com`.

OBJECT-ORIENTED · MULTIPLATFORM · SINGLE-SOURCE · C++

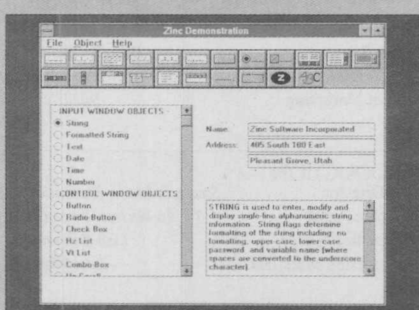
THINK ZINC



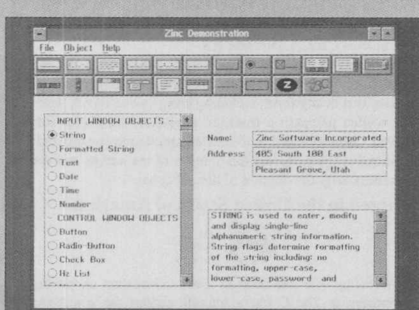
UNIX MOTIF



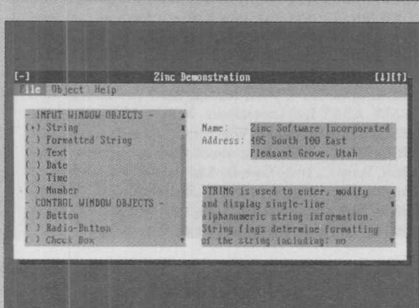
OS / 2 2.0



MS WINDOWS & WINDOWS NT



DOS GRAPHICS



DOS TEXT

ZINC™ APPLICATION FRAMEWORK™ 3.5

Multiplatform Flexibility From One Application Framework.

FLEXIBILITY *is an essential component in software design. Your development tools should allow you to easily incorporate new features and technologies into your applications without rewriting all of your code. That's a tall order if your development tools are designed like a straight-jacket. Zinc Application Framework 3.5 and Zinc Designer™ give you flexible and extendible support for Microsoft Windows, Windows NT, OS/2 2.0, UNIX Motif, DOS Graphics and DOS Text. And Zinc does it with ONE set of source code. Zinc's multiplatform, object-oriented architecture won't confine your application development options today... or tomorrow.*

FOR A FREE ZINC DEMO KIT, CALL US TOLL FREE TODAY AT 1.800.638.8665. IN EUROPE CALL +44 (0) 81 855 9918

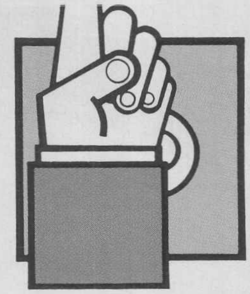
Z i n c

ZINC SOFTWARE INCORPORATED, 405 SOUTH 100 EAST, 2ND FLOOR, PLEASANT GROVE, UTAH 84062, TEL 801.785.8900, FAX 801.785.8996, BBS 801.785.8997.

EUROPE: ZINC SOFTWARE (UK) LIMITED 58-60 BERESFORD STREET, LONDON SE18 6BG, TEL +44 (0) 81 855 9918, FAX +44 (0) 81 316 7778, BBS +44 (0) 81 317 2310

✧ Request 126 on Reader Service Card ✧

Editor's Forum



Well, I made it past my 50th birthday. Being a 50-year-old computer programmer is definitely better than being 20 — you get more toys to play with and more autonomy in choosing what to do with them. But I confess that it's not as nice as being 30, or even 40 — I miss the energy that came with those relatively youthful milestones. My main consolation is that I still have some energy left, and I'm much wiser about how I spend it now than in years gone by.

I couldn't help but notice at 30 that many of my 40-year-old colleagues weren't as active in the trenches as I was. Ten years later, I found out why. With maturity in one's profession comes increasing demands to serve as caretaker rather than front-line contributor. Someone has to write all those proposals, job descriptions, requirements documents, requisitions, etc. They eat time like candy and sure don't resemble programming. But only the most dedicated techies can resist the siren lure of responsibility. The rest of us get suckered into acting like grownups.

I couldn't help but notice at 40 that many of my 50-year-old colleagues weren't even fighting interesting battles, or so it appeared to me at the time. They seemed to attend interminable meetings and talk about policy matters and other ephemeral abstractions. I mean, how important can it be to draft international standards, or procedures for software quality control, for heaven's sake? Now, after a decade or more of doing that sort of stuff, I've come to see the merit in it. I've learned how to play the guru, or the statesman, or the doddering old fool, as the need arises. I can even sit through a two-hour meeting without squirming (excessively).

I still write the odd bit of code, or the odd requirements spec, and it's more fun than ever. I spent the half-week before my birthday in New Jersey, beating on the draft C++ standard with Andy Koenig, Tom Plum, Bjarne Stroustrup, and others — and I have to admit it was mostly enjoyable. The computer business has never been more exciting than it is today. I have much to be grateful for.

When I stumbled into this field at the age of 19, I never dreamed it would consume my entire adult career. Or that it would bring me so many rewards. I can only hope that most of you who read this magazine can enjoy a comparable passion. May your candle burn equally bright.

So how does it feel to be half a century old? My favorite quote on that topic is from Lowell Thomas, who was asked on his birthday how it felt to be 80. He said, "It's not bad, considering the alternative."

P.J. Plauger

pjp@plauger.com

C++ Language Support Library

Introduction

I conclude my discussion of the language support portion of the library specified by the draft C++ standard. (See "Standard C: The Header `<exception>`," *CUJ,* February 1994, "The C Library in C++," *CUJ,* December 1993, "C++ Library Ground Rules," *CUJ,* November 1993, and "Developing the Standard C++ Library," *CUJ,* October 1993.)

"Language support" consists of those functions that can be called implicitly by C++ code, even when the code apparently contains no function calls. It also consists of the types required to declare and use those functions, as well as a few other related functions and types not directly needed to support the C++ language proper.

Standard C

Standard C has few such creatures (if any). You can argue that several type definitions are part of language support. The types `ptrdiff_t`, `size_t`, and `wchar_t` are defined in various headers so you can declare objects that have the same types as certain expressions. They are a way to convey otherwise unknowable (or hard to learn) information about these types from the translator to the program.

You can also argue that function `exit` is part of language support. The execution of any C program effectively occurs by evaluating the expression `exit(main(argc, argv))`. Saying such a thing simplifies descriptions — it ties together the effects of calling `exit` and returning from `main`, for example. But it doesn't have a dramatic effect on how you actually write C programs. You cannot, for example, provide your own version of `exit` and expect it to be called when `main` returns. (And many implementations don't really call `exit` when `main` returns, but some other underlying function instead.)

C++, on the other hand, offers numerous opportunities along these lines. You can trot up all sorts of functions that get control, either directly or indirectly, when one of the language support functions gets called. For example, in last month's discussion of exceptions I identified three functions that let you register *handlers,* or functions that get control under some circumstances:

- `set_terminate`, to specify a handler for calls to `terminate()`
- `set_unexpected`, to specify a handler for calls to `unexpected()`
- `xmsg::set_raise_handler`, to specify a handler for calls to `xmsg::raise()`

You can also derive a class from `xmsg` and override the virtual `xmsg::do_raise` to get control when certain exceptions get reported by executing code.

Thus, the draft C++ standard is a bit harder to write than the C Standard. In C, the implementation provides all library functions and you the programmer cannot displace them. The C Standard only has to describe a single interface between implementation and program. In C++, however, the program can displace functions otherwise supplied by the library. The draft C++ standard must spell out the environment promised to such a displacing function. And it must spell out what is expected of the displacing function so the program doesn't get surprised.

A handler for `terminate()`, for example, is not supposed to return to its caller. If you provide one that prints a message and returns, you can cause the library severe problems. The draft C++ standard says so. So when you read the descriptions that follow, remember that the "treaty" between programmer and implementor can be multifaceted. The extra complexity of the draft C++ standard is one of the prices we pay for extra flexibility in this area.

P.J. Plauger is senior editor of The C Users Journal. *He is convenor of the ISO C standards committee, WG14, and active on the C++ committee, WG21. His latest books are* The Standard C Library, *and* Programming on Purpose *(three volumes), all published by Prentice-Hall. You can reach him at* pjp@plauger.com.

longjmp. Similarly, the addition of *new* and *delete* to C++ essentially structure the use of *malloc* and *free*. By writing:

```
Thing *p = new Thing;
```

you are assured that the object of type *Thing* is properly constructed after it is successfully allocated and before it can be accessed through *p*. Similarly, the expression statement:

```
delete p;
```

ensures that the object is destroyed before its storage is deallocated.

You don't have to include any headers before writing expressions like these — *new* and *delete* are indeed built right into the language. But you can also play a variety of games with storage allocation if you choose. To do so, you begin by including the header *<new>*. Listing 1 shows a representative version of this header. I omit the extra superstructure required by namespaces, because it is distracting and still in a state of flux.

The simplest game you can play is to gain control when space for the heap is exhausted. The function *set_new_handler* lets you register a handler for this condition. In principle, the draft C++ standard says you can "make more storage available for allocation and then return," but it fails to describe a portable way to do so. one or more allocated objects may also help, but even that is not guaranteed. More likely, you will want to throw an exception or terminate execution at this point.

xalloc Exceptions

The default "new handler" does, in fact, throw an exception now. As I described last month, all library exceptions are derived from the base class *xmsg*. Moreover, all exceptions are thrown by calling *ex.raise()*, for some object *ex* of class *xmsg*. Unless you seize control of the process in one of the ways I described last month, the eventual outcome is that a failed allocation will throw an exception, which will in turn terminate execution of the program.

This is a significant change from universal past practice, which has been to quietly yield a null pointer as a result of the *new* expression. The Library Working Group of X3J16/WG21, the joint ANSI/ISO standards committee for C++, anguished quite a bit before recommending this change. The joint committee anguished a bit more in turn. But eventually, the predominant wisdom was that the Standard C++ library had bloody well better use the full language in this case, not just the bits that were available when *new* and *delete* were first added to C++.

A persuasive argument is that very few programs truly check *all new* expressions for null pointers. Those that don't may well stumble about when the heap is exhausted — they're almost certainly better off dying a clean death. Those that do check all such expressions often simply abort — the path to abnormal termination is now just slightly different. It is only those few sophisticated programs that try to do something nontrivial when heap is exhausted that need a bit of rewriting. Most of the joint committee felt this was a necessary price to pay to introduce exceptions at this critical juncture.

Even so, some sympathy remains for being able to revert to the old behavior. For a variety of reasons, the Library Working Group has not spelled out a portable way to do so. But the group has

Listing 1 *The header <new>*

```
#ifndef _NEW_
#define _NEW_
#include <exception>
                // class xalloc
class xalloc : public xruntime {
protected:
//      virtual void do_raise();
public:
        xalloc(const char * = 0, const char * = 0);
        virtual ~xalloc();
};
                // function and object declarations
fvoid_t *set_new_handler(fvoid_t *);
void operator delete(void *);
void operator delete[](void *);
void *operator new(size_t);
void *operator new[](size_t);
void *operator new(size_t, void *);
extern fvoid_t (*_New_hand);
#endif
```

identified what it thinks should be a common extension. Calling *set_new_handler* with a null pointer argument is otherwise undefined behavior. It seems natural to use this nonportable call as a way for implementations to know that they should revert to the older behavior.

Replacing *operator new(size_t)*

If you want more certain control over the business of allocating storage, your best bet is to provide your own versions of *operator new(size_t)* and/or *operator delete(void *)*. These functions have a peculiar dispensation — the library provides a version of each, but you can "knock out" those versions by defining your own. (Only the array versions of these two operators, described below, also enjoy this special status within the Standard C++ library.)

Before I go into details, please note an important distinction here. When you write:

```
Thing *p = new Thing;
```

the *new Thing* part is called a "*new* expression." It calls *operator new(size_t)* to allocate storage, but it also does other things, such as constructing the newly allocated object. All that *operator new(size_t)* has to worry about is providing the number of requested bytes, suitably aligned, or dealing with heap exhaustion. Listing 3 shows one way to write this function.

Similarly, when you write:

```
delete p;
```

the *delete p* part is called a "*delete* expression." It calls *operator delete(void *)* to free storage, but it first destroys the object (only if the pointer is not null, of course). All that *operator delete(void *)* has to worry about is freeing storage for the object. Listing 4 shows one way to write this function.

So one thing you might do is replace *operator delete(void *)* with a function that doesn't really free the storage. That could be handy while you're debugging a program, provided of course that you have enough heap to run your test cases.

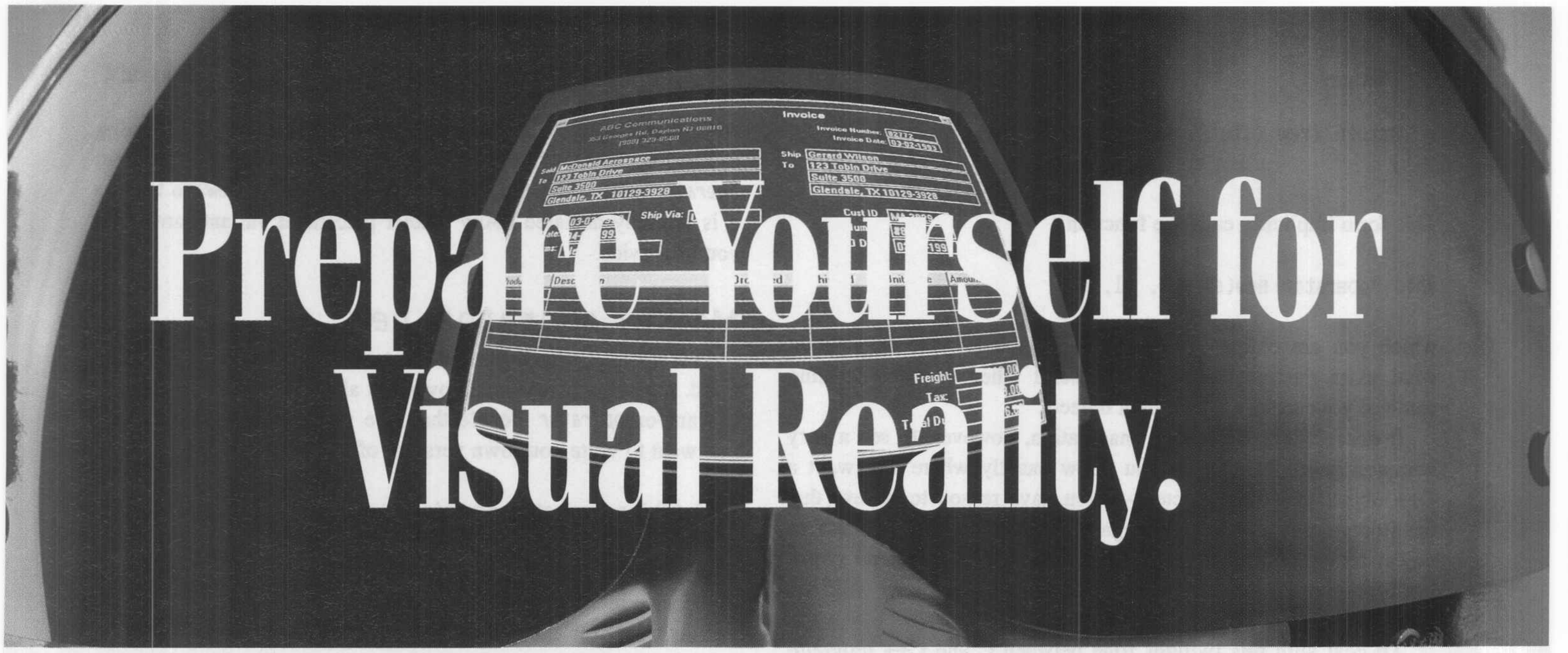
Or you might replace both *operator new(size_t)* and *operator delete(void *)* with versions that are simpler, or faster, or more sophisticated than the library versions. It is important to replace both, because the latter function in the library only knows how to free storage for objects allocated by the former.

In either case, you probably don't have to bother with *set_new_handler*. You are at liberty to do whatever you want when you run out of heap. No need to call the new handler, which you can't easily do portably anyway.

Placement Syntax

Yet another latitude granted by the C++ language is to provide an arbitrary set of additional arguments in a *new* expression, as in:

```
Thing *get_special(T1 stuff,
                   T2 more_stuff)
    {
```



Prepare Yourself for Visual Reality.

Introducing ProtoGen+. Visual tools with the most awesome workbench ever created for Windows development.

The future has arrived—a complete point-and-click, WYSIWYG workbench that lets you create dazzling applications without writing a line of code.

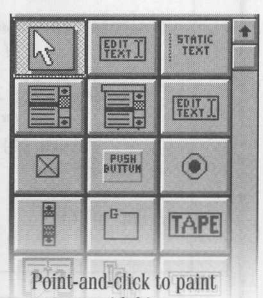
Discover the ease and productivity of visual development!

- Visually develop screens
- Create a menu and connect screens & dialogs
- Test the application's screen flow in a live environment
- Instantly generate source code in Pascal, C or C++

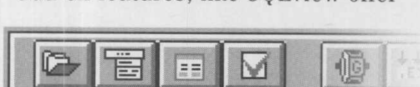
Paint your screens. Design a menu and link screens together. Test the flow in a live environment, and generate code for ANSI C, C++ for OWL or MFC or Pascal with objects. It's that easy.

And this open! ProtoGen+ will work with your database, compiler, libraries and extensions. Powerful add-on features, like SQLView offer workbench access to multiple databases to develop client/server and xBase applications. Snap-in components make ProtoGen+ open to future development technologies—whatever they may be.

ProtoGen+ is easy to learn, speeds your development cycle and protects your investment by generating C,C++ and Pascal. We guarantee you'll prototype and generate exciting applications faster than you ever thought possible!



Point-and-click to paint screens with bitmaps, icons, tables, data validation, custom colors, fonts, 3D effects, visual toolbars, status lines, balloon help, MDI and more!



Bring your applications to life using the latest visual design tools!

The most powerful, open set of Visual Development Tools ever!

Build windows, forms, dialog boxes, tool bars	Dialog Editor	Menu Designer	Quickly create a menu using templates
Output C, C++ and Pascal with Objects	Code Generator	ProtoView Screen Manager	Data validation, 3-D effects, MDI and more
Create new designers! Source included	Custom Visual Designer	Win-Control Library	Rich library of visual control objects

Snap-in Code Generators

License our technology to create new code generators

MONEY BACK 30 DAY GUARANTEE

Fasten your seatbelt for ProtoGen+!

Only **$199** (list price $395)

1-800-231-8588

Ask for Ext. 40

In NJ, call (908) 329-8588

ProtoGen+'s SQLView access to multiple databases is available at an additional price; ask about it when you call.

PROTOVIEW™

The Visual Development Edge™

All products named are trademarks of their respective companies. ©1993 ProtoView Development

✧ Request 376 on Reader Service Card ✧

```
    return (new (stuff, more_stuff) Thing);
    }
```

This form implicitly calls the function:

```
void *operator new(size_t, T1, T2);
```

which you are obliged to supply. I leave it to your imagination what extra parameters might be useful when you're allocating some of your more sophisticated objects.

It doesn't take too much imagination, however, to see a very common need. Sometimes you know exactly where you want a C++ object to be constructed — you have reason to believe that the storage area *X* is large enough and suitably aligned to hold an object of type *Thing*. Moreover, you're confident that no object has been constructed there already for which a destructor will later be called. (Whew!)

To deal with this twilight zone between C and C++ programming, you can write:

```
Thing *p = new ((void *)&X) Thing;
```

This, naturally enough, calls the function:

```
void *operator new(size_t, void *);
```

which can simply return its second argument, as shown in Listing 4. The Standard C library provides this one version of a placement *operator new*. (Don't forget to include the header *<new>* to be sure it is properly declared.) Any fancier placement variants are up to you to provide.

Member *operator new*

Yet another way exists for controlling how objects get allocated. For any class, you can overload all the variants of *operator new* and/or *operator delete* that I've mentioned so far. Perhaps you want to write your own versions of:

```
void *Thing::operator new(size_t);
void Thing::operator delete(void *);
```

that does a really fast job of allocating and freeing objects of class *Thing*. It can, for example, maintain a list of previously freed objects and hand them back quickly for future allocation requests. Unless you really get tricky, you can even ignore the *size_t* first argument to all variants of *operator new*, since you know how big a *Thing* is likely to be. (How do you get tricky? Well, you can make *operator new* virtual in the base class and fail to override it in a derived class. But thinking about things like that gives me a headache.)

So you see that you can exercise pretty fine control over how all objects, or even individual objects, get allocated.

Listing 2 *The function* operator new(size_t)

```
// operator new(size_t) REPLACEABLE function
#include <stdlib.h>
#include <new>

void *operator new(size_t size)
        {       // try to allocate size bytes
        void *p;
        while ((p = malloc(size)) == 0 && _New_hand != 0)
                (*_New_hand)();
        return (p);
        }

// End of File
```

Listing 3 *The function* operator delete(void *)

```
// operator delete(void *) REPLACEABLE function
#include <stdlib.h>
#include <new>

void operator delete(void *p)
        {       // free an allocated object
        free(p);
        }

// End of File
```

cation and freeing of arrays. You can, for example, write:

```
Thing *p = new Thing[N];
```

to allocate an array of *N* elements each of type *Thing*. Each of the elements is constructed in order, starting with the first (element zero). In this case, you *must* write the expression statement:

```
delete[] p;
```

to delete the array, not just a simple:

```
delete p;
```

as before. Why? Because the "array *new* expression" above has to somehow memorize how many elements *N* it has allocated. It needs to know to locate this memorized information and use it to destroy the appropriate number of elements and free the appropriate amount of storage. Yes, some existing implementations of C++ let you be cavalier about deleting arrays the wrong way, but don't count on that license in a portable program.

This requirement presents another problem. What happens if you've provided a member *operator new(size_t)* for class *Thing*, as above? It cannot, in general, know whether it's being asked to allocate storage for a single element or a whole array. (Remember the potential trickery I mentioned above.) So what C++ has done in the past is to ignore any such member functions and call the global *operator new(size_t)* for all array allocations. This has been a less than satisfactory solution.

The joint committee has plugged this control gap by permitting you to define functions such as the members *operator[] new(size_t)* and *operator delete(void *)*. Defining these functions gives you control over the allocation and freeing of

Listing 4 *The function* operator new(size_t, void *)

```
// operator new(size_t, void *)
#include <new>

void *operator new(size_t, void *p)
	{	// allocate in place
	return (p);
	}

// End of File
```

cated, by the way. An array *new* expression can ask for extra storage for its own bookkeeping, so you'd better honor the *size_t* argument blindly. But at least you can maintain private storage pools now for array objects.

For completeness, the draft C++ standard also includes global versions of:

```
void *operator new(size_t);
void operator delete(void *);
```

The library versions of these functions just turn around and call the non-array library versions, so I won't show you the code for them. And you can indeed knock these functions out with your own definitions, but I'm not sure why you'd bother. Doubtless, someone more clever or perverse than I can make a case for *any* feature added to C++.

Type Information

There is one last aspect to the language support library. It is rather small compared to exceptions (all of last month's installment) or storage management (most of this month's). I tack it on here for completeness.

Another relatively recent significant addition to the draft C++ standard is "run-time type identification" (or RTTI, for short). Basically, it adds the operator `typeid` for obtaining various bits of information on the type of an object (or expression). The operator yields an object of class `typeinfo`, defined in the header *<typeinfo>*. Listing 5 shows one way to write this header.

The exception `badtypeid` is reported in those cases where the type cannot be determined statically at translation time. If, in the process of chasing down the actual object, the program encounters a null pointer, you can guess what happens.

(If you're put off by all these names made from words run together, you're not alone. There's a good chance that the joint committee will approve a new naming convention that involves a more liberal use of underscores to separate component words in names. So don't be surprised if many of these compound names change in the coming months.)

What can you do with an object of class `typeinfo`? Well, you can obtain some sort of name for the type, for one thing. `typeinfo::name()` yields a null-terminated multibyte string (or NTMBS, in the jargon of the draft C++ standard) that presumably says something meaningful about the type. There are no standard names defined, so far, not even for the builtin types.

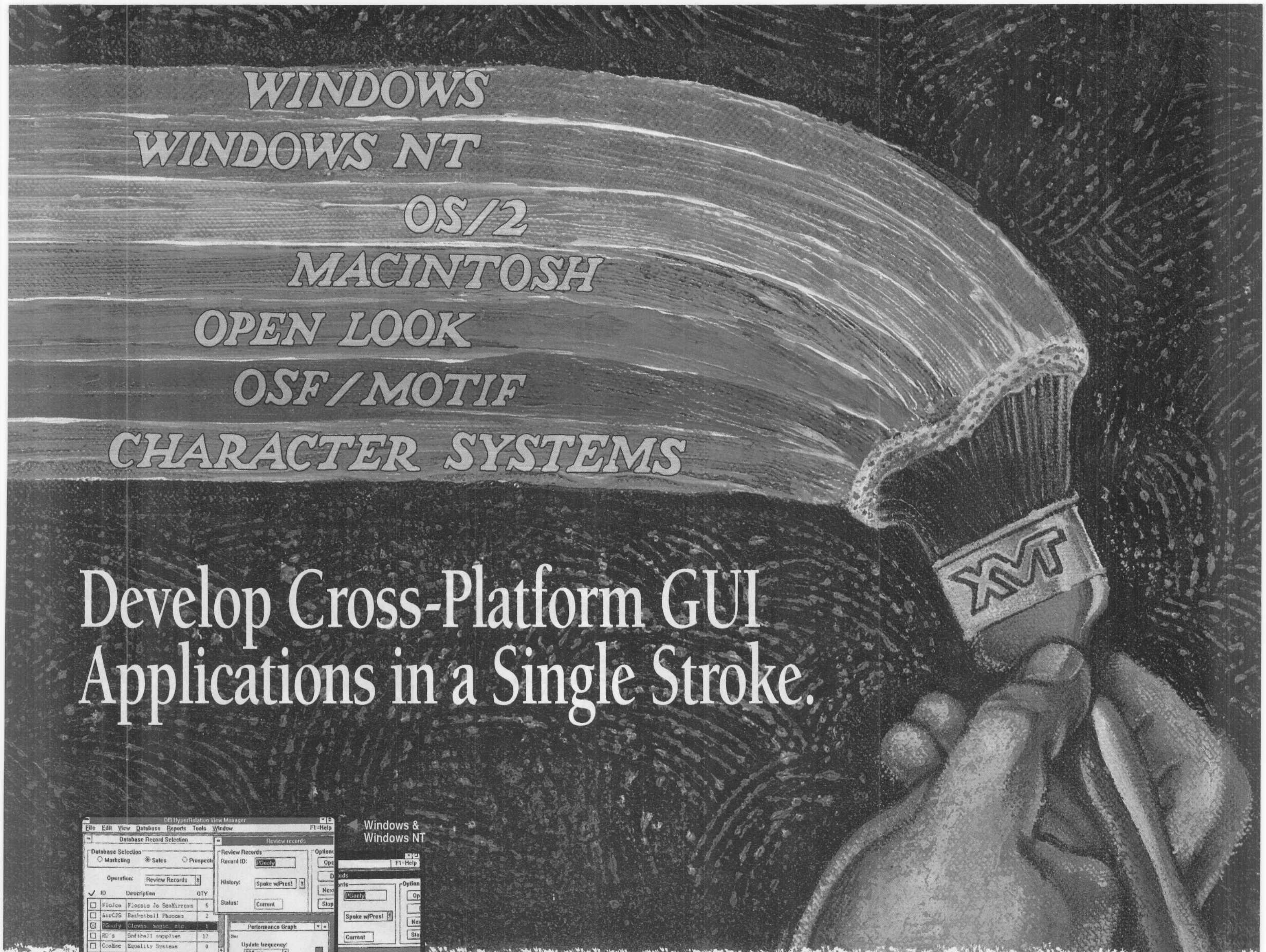
You can also compare two objects of class `typeinfo` for equality or inequality. Within any given program, you can expect two such objects to compare equal only if they derive from two expressions of the same type. Don't expect to be able to remember these critters in files, however, and check for type equality across programs. Even running the same program twice doesn't promise to yield the same representation of a `typeinfo` object for the same type each time. (I have indicated that the type information can be represented as an `int`, but that is just illustrative, not a requirement.)

Finally, you can impose an ordering on all the types within a program. `typeinfo::before(const typeinfo&)` returns nonzero for an object that represents a type earlier in the pecking order than the argument object. Once again, however, no promises are made about the rules for determining this order, or whether they're even the same each time you run the program.

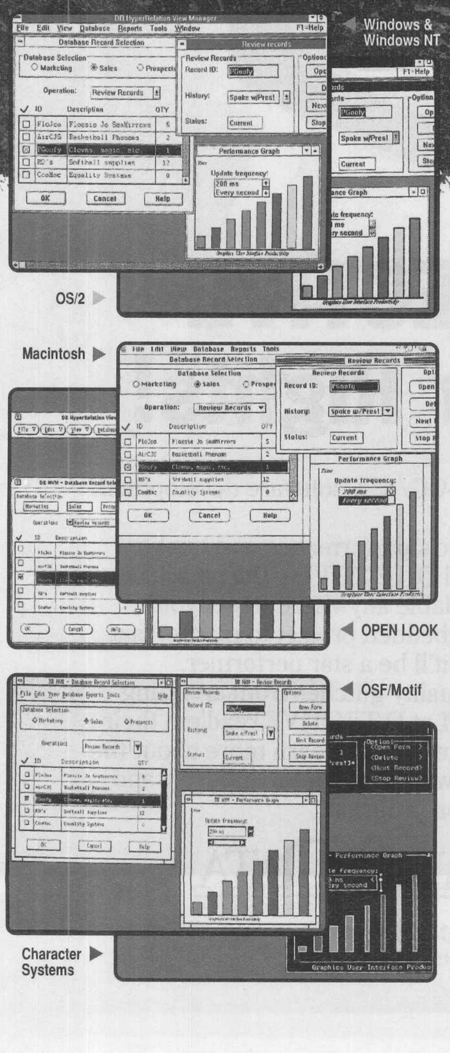
I'm sure far more can be said about the uses of RTTI, but I'm not the one to say it at this point in my career. Even if I were, this is not the place to say it. For now, you know what the standard C++ library has to know about RTTI. □

Listing 5 *The header <typeinfo>*

```
#ifndef _TYPEINFO_
#define _TYPEINFO_
                    // class badtypeid
class badtypeid : public xlogic {
protected:
//      virtual void do_raise();
public:
        badtypeid();
        virtual ~badtypeid();
        };
                    // class typeinfo
class typeinfo {
        const char *_Name;
        const int _Desc;          // implementation dependent
        typeinfo(const typeinfo&);
        typeinfo& operator=(const typeinfo&);
public:
        virtual ~typeinfo();
        int operator==(const typeinfo&) const;
        int operator!=(const typeinfo& _Rop) const
                {return (!(*this == _Rop)); }
        int before(const typeinfo&);
        const char *name() const {return (_Name); }
        };
#endif

// End of File
```



Develop Cross-Platform GUI Applications in a Single Stroke.



Master the art of multi-platform GUIs.

XVT Software is the leading choice of world-class developers for one reason: It is the simplest, quickest path to building quality applications that port to every GUI without compromises in look-and-feel or performance. Plus, it's easier to learn and use than native toolkits, so your time and effort goes into your application, not your GUIs.

XVT gives you simultaneous original GUIs.

Because XVT uses native GUI objects, your application is indistinguishable from one written directly to the native toolkit. Through our layered architecture, you achieve equivalent cross-platform functionality appropriate to each GUI, without the overhead and inflexibility of proprietary emulation-based systems.

XVT puts complete C/C++ solutions at your fingertips.

NEW! XVT-PowerObjects

XVT Development Solutions for C include an Interactive Design Tool. Solutions for C++ include an object-oriented application framework. Both include the XVT Portability Toolkit.

When combined with in-depth consulting, training and support, plus a wide range of Partners products, XVT forms the most comprehensive and advanced solution for developing completely portable GUI applications.

✧ Request 197 on Reader Service Card ✧

Developers judge XVT to be a masterpiece.

XVT is the base document for the IEEE's GUI standardization effort. Our thousands of customers include internal and commercial developers like: Alcoa, Amoco, AT&T, Avis, Ford, General Motors, Grammatik/Reference Software, Kodak, Lockheed, NCR, NEC, NIST, Novell, Rockwell, Siemens, Sony, Southwestern Bell, Tandem, Uniplex, Unisys, US Army and US West.

Call now for a Free XVT Demo and Technical Overview.

1-800-678-7988

XVT SOFTWARE INC

The portable GUI development solution.

XVT Software Inc. 4900 Pearl East Cir. Boulder, CO 80301
(303) 443-4223 FAX (303) 443-0969

For European inquiries, contact: Precision Software GmbH
Phone: 49 0 61 03/37 94 0 Fax: 49 0 61 03/36 95 5

Symbolic Access To Embedded Controllers

Odd A. S. Olsen and Petter H. Heyerdahl

Introduction

A PC often functions as the user interface, debugging tool, and general supervisor of an embedded controller. With this arrangement it is important for the programs that transfer parameters between the PC and the controller to maintain agreement on the names and meanings of all variables. If the PC sets parameter 63 to the value of 123, for instance, the PC and the controller must agree on what parameter 63 is and what the value 123 represents. This consistency is especially at risk during development because new parameters are sometimes introduced on-the-fly and often end up in different locations on the two computers. The processors may not even agree on a format for the values. (An Intel PC could be storing numbers in big-endian format while a Motorola controller might want them in small-endian format.)

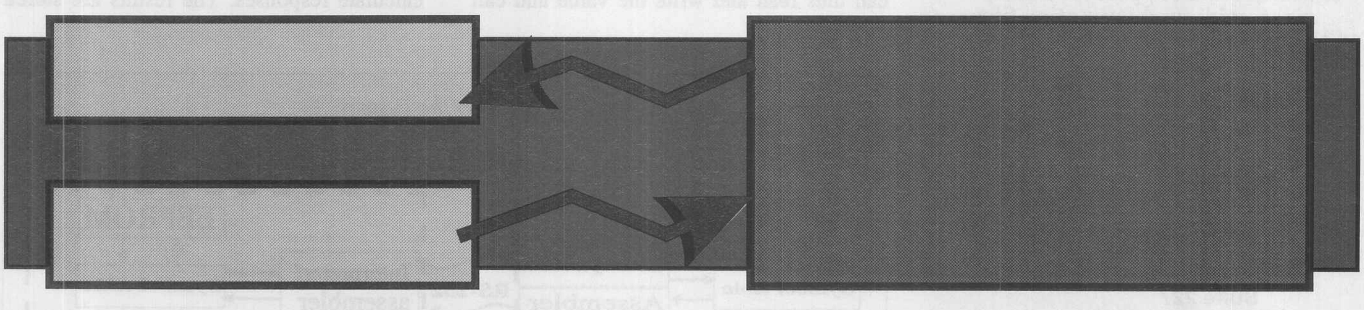
A symbol table is an efficient solution to the consistency problem because it allows the data structures of the PC and controller to develop separately, yet links the two systems with a simple communication protocol. By this method, which resembles the message format found in the general-purpose interface bus (GP-IB), values are referenced by their symbolic name, e.g. `measured_pH`, `heater_power` etc. We used this principle to control a group of bioreactors. Each reactor is controlled by an embedded controller which communicates with a supervising PC for operator instructions and data logging.

How Things are Connected

Figure 1 illustrates the information flow in the system. In our implementation the PC is always the initiator of communication and the embedded controller only responds to received messages. The most important entries in the symbol tables are the parameter names and their values. (In this context a parameter is more general than a constant. It can also represent measured data, debug information, etc.) Parameter values move from the PC symbol table to the controller symbol table through messages sent over the RS-232 line. The PC symbol table can be altered either by accessing the user interface or by causing the PC to read a refreshed version of the parameter file. The new data is then sent to the symbol table in the embedded controller. The controller symbol table can thus be changed from the PC, or through the measurement and control algorithms of the controller itself. Parameters for the control algorithms are stored in the EEPROM, enabling the controller to initialize its symbol table values at start-up and maintain its control process by itself should the PC fail.

The Symbol Tables

Both the PC program and the embedded controller program are centered on their respective symbol tables. The structure of the PC symbol table is:



Odd A.S. Olsen and Petter H. Heyerdahl received their Master of Engineering degrees in Engineering Cybernetics at the Norwegian Institute of Technology, where Mr. Olsen later received a Ph.D. He is currently an independent consultant, developing electronics and programs for embedded controllers. Mr. Heyerdahl is associate professor at the Agricultural University of Norway, Department of Agricultural Engineering. Odd may be contacted at Jutulveien 11, N-0852 Oslo, Norway or by the Internet: `odd.olsen@itf.nlh.no`.

```
typedef struct {
    char *name;
    int ival;
    double fval;
    void *(*scalefunc)(void *);
    char eeProm;
    char file;} symTabEntry;
```

Each of the process variables maintained by the controller (temperature, oxygen level, pH, etc.) is represented as a record in the symbol table. Every record in the table contains a unique name (e.g. `measured_pH`), an integer or double floating-point value, and a pointer to an optional scaling function. The table also contains two flags: `eeProm` and `file`. If `eeProm` is set to `TO_EE`, the record will be transferred to the controller upon start-up, and will be stored in the controller `EEPROM` if its value is different from the one already residing there. The `file` flag indicates whether the current record contains data associated with the system's parameter file. This parameter file contains parameter names (of process variables and other system variables) and their values. If the system finds a particular parameter name in the file during startup, the system copies the parameter's value into the record, and sets a bit in the `file` flag. Likewise, if the user later wants to save the current parameter values back to the file, the system will save only those parameters whose `file` flags are set. While the system is operating, a record holds a parameter's value in either `ival` (for integer parameters) or `fval` (for floating-point parameters).

The user interface is also oriented to the symbol table. The user can change parameters by choosing a parameter window. Each parameter entry field knows the pointer to its entry in the symbol table. It can thus read and write the value and call the scaling function. When the user changes a parameter, the new value is immediately scaled from floating-point to integer and transmitted to the controller. Because values are referred to by name rather than by pointer, the set-up of the parameter windows is simplified.

The symbol tables are alphabetically sorted, which allows the processor to use a binary search when looking for a name. (A binary search is faster than a linear search, but if the tables were large, I would consider using hash-tables.) The programmer will now and then insert new entries to the tables at a wrong position. On start-up both the PC and controller programs therefore go through their tables and check for alphabetic order. If unordered elements are found, the function issues an error message.

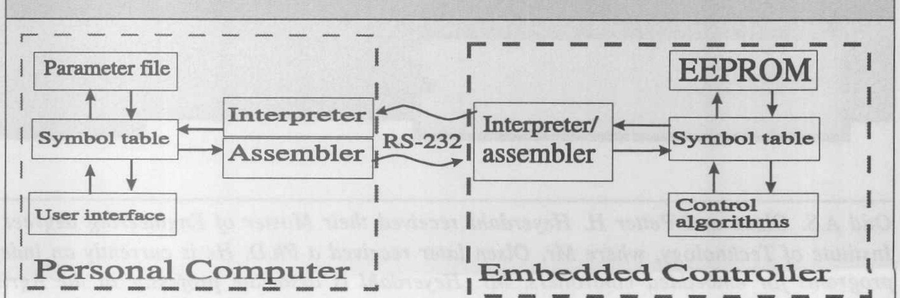
The structure of controller's symbol table is

```
typedef struct {
    char *name;
    int ival;
    char *(*func)(char *);
    int eeOffset;} symTabEntry;
```

`name` is the name of the parameter, `ival` the value, and the function pointer either a function that can be invoked by a message or a hook for individual processing of received parameters. `eeOffset` is the `EEPROM` address where the parameter is stored. (Parameters that are not saved in `EEPROM` have an offset value of –1.)

The controller's program runs periodically, e.g. every five seconds. The program first reads all measurements and stores the values in the symbol table. The control algorithms then take their values and parameters from the symbol table and calculate responses. The results are stored

Figure 1 *Information flow through the system*



name is *pHerror=pHsetpoint-pHmeasured*. This can be programmed as:

```
FindSymbol("pHerror")->ival=
FindSymbol("pHsetpoint")->ival
- FindSymbol("pHmeasured")->ival;
```

`FindSymbol` returns a pointer to the symbol table entry with the given name. However, less typing and a faster program are achieved by initializing pointers to the symbol table entries at start-up:

etc. and coding the algorithm as

```
*ppHerror= *ppHsetpoint - *ppHmeasured;
```

At start-up the symbol tables are initialized according to the following sequence. First the tables are initialized with the values specified at compile time. The controller then reads values from the `EEPROM` into its table. The PC reads a parameter file, which may change some of the values in its table. The PC program will then transfer those values having flag `TO_EE` set to the controller `EEPROM` and symbol table.

Message Format

The messages between the PC and controller are ASCII strings sent over an RS-232 connection. Before transmission the message assembler adds a checksum. The receiver checks and removes the checksum from the message before passing the message to the message interpreter.

Each message consists of one or more submessages. The submessages and their elements can be separated by spaces and have the following format:

```
<name><operator>[<value>]
```

Listing 1 *Message interpreter definitions and function prototypes*

```
/* parsdef.h */
/* No copyrights claimed */
#define ERROR            1
#define EMPTY            2
#define ASSIGN           3
#define REQUEST          4
#define TO_EEPROM        5
#define IS               6
#define COMMAND          7
#define INTEGER          8
#define NAME             10
#define NAME_ERROR       11
#define OP_ERROR         12
#define VAL_ERROR        13
#define END_ERROR        14
#define POOL_ERROR       15
#define UNDEF_SYMB       16
#define NOT_EEPROM       17
#define UNDEF_FUNC       18
#define MAX_TOKEN_LEN    10
#define MAX_STATEMENTS   20
#define STRINGPOOL       80
#define MESSAGELENGTH    80

typedef struct {
    int command;
    int type;
    char *name;
    int  value;
} toDoList;
```

The name field is the symbolic name of a parameter or a command. The operator is a single character as given in Table 1. For messages with an associated value, the value field is the numerical value of the parameter. The name must begin with a letter (a-zA-Z), followed by a number of letters, digits, or underscores (a-zA-Z0-9_). In our implementation the value field is always an integer because all processing in the controller is integer based.

To add other value types the programmer need only define new operators and modify the structures and programs accordingly. A floating-point type is useful in some systems. A string type can also be of use, for example to transfer strings directly to an operator display on the controller. In a multi-processor embedded system, the string type can be used to transfer messages verbatim to subprocessors.

The following message transfers `temp_setp=20` to `EEPROM`, sends `delay=10` to the symbol table, requests the present value of `temp`, and executes the function `pwr_sav`.

```
temp_setp>20 delay=10 temp? pwr_sav!
```

The response might be

```
temp:22 pwr_sav#16
```

The error message indicates that `pwr_sav` was not found in the symbol table of the controller. (Such error messages are hopefully only encountered during program development.) In this case the message indicates a discrepancy between the PC and controller programs.

Message Interpretation

The interpreter parses the received messages into a task list which is handed over to an execution function. The structure of the list records is:

```
typedef struct {
    int command;
    int type;
    char *name;
    int value; } toDoList;
```

`command` is a value specifying the command, `type` the type of the value (in this case always `INTEGER`), `*name` a pointer to the name of the parameter, and `value` the numerical value of the parameter.

Table 1 *Message formats and operators*

`<name> = <value>`	Assign value to parameter name
`<name> ?`	Request the value of parameter name
`<name> > <value>`	Transfer value to the *EEPROM*
`<name> : <value>`	Current value of parameter name
`<name> !`	Execute name-command
`<name> # <value>`	Error code value associated with name

In the controller the interpreter and reply assembler are integrated. In the PC, however, parameters are sent through a message assembler and replies decoded in a separate interpreter. The receiver is interrupt driven and executes the interpreter after a full message has arrived. The interpreter places the received values into the symbol table and transfers error messages to the user interface. The PC interpreter resembles the controller interpreter, which I am about to describe.

A Sample Application

This slightly modified version of the controller's interpreter and message assembler will illustrate message handling and symbol table operations. (This version runs on a PC.) Listing 1 presents the definitions and function prototypes; Listing 2 shows the main program and message interpreter.

The main program reads a message from the keyboard. It parses the message, then prints and executes the task list `toDo`. The task list is a list of structures with one entry for each subcommand. The `Parse` function assumes the message is formated as defined in Table 1. Since the grammar is quite simple, there is no need for recursive descent or other strategies used in compilers. There are several tests that check adherence to the format, and issue error messages if discrepancies are found. (This is most valuable during program development.) Finding an error stops the message interpretation. Inserting an `EMPTY` command terminates the list.

`GetNextToken` reads the next token in the message string. If the first character encountered is a letter, the token is a name. If it is a

Listing 1 *continued*

```
typedef struct {
    char *name;
    int ival;
    char *(*func)(char *);
    int eeOffset;     /* -1 if not saved in eeprom */
} symTabEntry;

char        *Assign(toDoList *pL, char *pTx);
void         DoCommands(toDoList *pL);
symTabEntry *FindSymbol(char *name);
char        *GetNextToken(char *begin, char *token, int *type);
void         Parse(char *message, toDoList *pL);
void         PrintToDo(toDoList *toDo);
char        *Request(toDoList *pL, char *pTx);
char        *Reset(char *ptr);
char        *RunCommand(toDoList *pL, char *pTx);
char        *SayError(toDoList *pL, int err, char *cp);
int          StoreToken(char **strp, char *token);
int          SymCmp(symTabEntry *a, symTabEntry *b);
char        *ToEeprom(toDoList *pL, char *pTx);
char        *TxBuffer(void);
void         WriteEeprom(symTabEntry *pSym, int type);

/* End of File */
```

digit, the token is a value. If the first character is neither a name nor a value, the token is an operator. The function then copies the token into the token string of the parser and sets the *type* parameter according to the type. The size of the token-string (*MAX_TOKEN_LEN*) must be larger than the longest token that can occur. The *type* parameter is set equal to the operator's defined constant.

Parser calls *StoreToken* to save the encountered names in a string pool. This pool is recycled for each message by setting *pPool=stringPool*. The pool size (*STRINGPOOL*) must be large enough to store all the names that can occur in one message. The address of the name is stored in the *name* element of the structure.

The task list *toDo* can now be processed by calling *DoCommands*. This function is essentially a loop which executes the commands through a switch statement. However, it first initializes a pointer to the beginning of the *txBuffer*, where the response message is stored. This buffer might be local to the more hardware-dependent parts of the program and not globally accessible, so this requires a function call to obtain the pointer. All functions called in *Docommands* maintain the buffer pointer by accepting it as an argument and returning the possibly changed value.

SayError writes an error message to the transmit buffer. It receives a pointer to the task list, where it finds the name relating to the error, and the error number.

Listing 2 *The message interpreter and assembler for the embedded controller, implemented on a PC*

```
/* pars.c */
/* no copyrights claimed */
#include <stdio.h>
#include <stdlib.h>
#include <ctype.h>
#include <string.h>
#include "parsdef.h"

static toDoList toDo[MAX_STATEMENTS];
static char stringPool[STRINGPOOL];
static char *pPool, *poolEnd;
static char message[MESSAGELENGTH];
static char *messList[]= {
    "EMPTY","error","empty","assign","request",
    "to_eeprom","is","command","integer","float",
    "name","name_error","op_error","val_error",
    "end_error","pool_error"
};

main()
{
    while(1) {
        pPool= stringPool;
        poolEnd= stringPool+STRINGPOOL-1;
        printf("\nmessage: ");
        gets(message);
        if(message[0]=='.') break;
        Parse(message, toDo);
        PrintToDo(toDo);
        DoCommands(toDo);
    }
}

/* first, the parsing */

void Parse(char *message, toDoList *pToDo)
{
    char *pC, token[MAX_TOKEN_LEN+1];
    int type, i;
    pC= message;
    for(i=0; i<MAX_STATEMENTS; i++) {
        (pToDo+1)->command= EMPTY; /* mark end */
        if(*pC=='\0'){pToDo->command= EMPTY; return;}
        /* get name */
        pC= GetNextToken(pC, token, &type);
        if(StoreToken(&pToDo->name, token) != 0)
            { pToDo->command=POOL_ERROR; return; }
        if((type==ERROR)||(type!=NAME))
            { pToDo->command= NAME_ERROR; return; }
        if(*pC=='\0') {pToDo->command=EMPTY; return;}
        /* get operator */
        pC= GetNextToken(pC, token, &type);
        if(type==ERROR)
            {pToDo->command=OP_ERROR; return;}
        pToDo->command= type;
        /* get value */
        if((type==ASSIGN)||(type==TO_EEPROM)||
          (type==IS)) {
            if(*pC=='\0')
                {pToDo->command=VAL_ERROR; return;}
            pC= GetNextToken(pC, token, &type);
            pToDo->type= type;
            if(type==INTEGER)
                pToDo->value= atoi(token);
            else {pToDo->command= VAL_ERROR; return;}
        }
        else pToDo->type= INTEGER;
        if(pToDo->command== EMPTY) return;
        pToDo++;
    }
    pToDo->command= END_ERROR;
    return;
}

char *GetNextToken(char *begin, char *token, int *type)
{
```

The functions *Assign*, *Request*, *ToEeprom*, and *RunCommand* each begin by getting a name from the task list and looking it up in the symbol table. If the name isn't found, they write an error message to the transmit buffer.

Listing 2 *continued*

```
    char *pC, *pT;
    int i;
    pC= begin;
    pT= token;
    *token= '\0';
    *type= EMPTY;
    if(*pC == '\0') {return pC;}
    /* remove leading spaces */
    while(*pC==' ') pC++;
    if(*pC=='\0') return pC;
    if(isalpha(*pC)) { /* name */
        *type= NAME;
        *pT++= *pC++;
        for(i=1; i<MAX_TOKEN_LEN; i++) {
            if((isalpha(*pC)) || (isdigit(*pC))
                || (*pC=='_')) *pT++= *pC++;
            else {
                *pT= '\0';
                return pC;
            }
        }
        *type= ERROR;
    return pC;
    }
    else if((isdigit(*pC))||(*pC=='+')||
        (*pC=='-')) { /* number */
        *pT++= *pC++;
        for(i=1; i<MAX_TOKEN_LEN; i++) {
            if(isdigit(*pC)) *pT++= *pC++;
            else {
                *pT= '\0';
                *type= INTEGER;
                return pC;
            }
        }
        *type= ERROR;
        return pC;
    }
    else if(*pC== '=') *type= ASSIGN;
    else if(*pC== '?') *type= REQUEST;
    else if(*pC== '>') *type= TO_EEPROM;
    else if(*pC== ':') *type= IS;
    else if(*pC== '!') *type= COMMAND;
    else {*type= ERROR; return ++pC;}
    return ++pC;
}

int StoreToken(char **ppName, char *token)
{
    int length;
    *ppName= pPool;
    length= strlen(token)+1;
    if((pPool+length)>=poolEnd) return -1;
    strcpy(pPool, token);
    pPool+= length;
    return 0;
}

/* and now, the action */

static symTabEntry symTab[]= {
```

The *Assign* function inserts the value in the symbol table. The *Request* function reads the value from the symbol table and generates a response submessage. *ToEeprom* puts the value into the symbol table and checks if the parameter has a place in the EEPROM. If *eeOffset* is greater than or equal to zero, it writes the value. If not, it issues an error message. *RunCommand* executes the program pointed to in the symbol structure. If the pointer is NULL, *RunCommand* generates an error message.

Assign, *Request* and *ToEeprom* all check for a function hook before returning. If they find one they call it. *Assign*, *Request*, and *ToEeprom* also maintain the transmitter buffer pointer so they can write to the buffer.

The program was compiled with Borland TurboC++ version 3.0. The library functions are all UNIX and ANSI defined, so using other compilers should not present any problem.

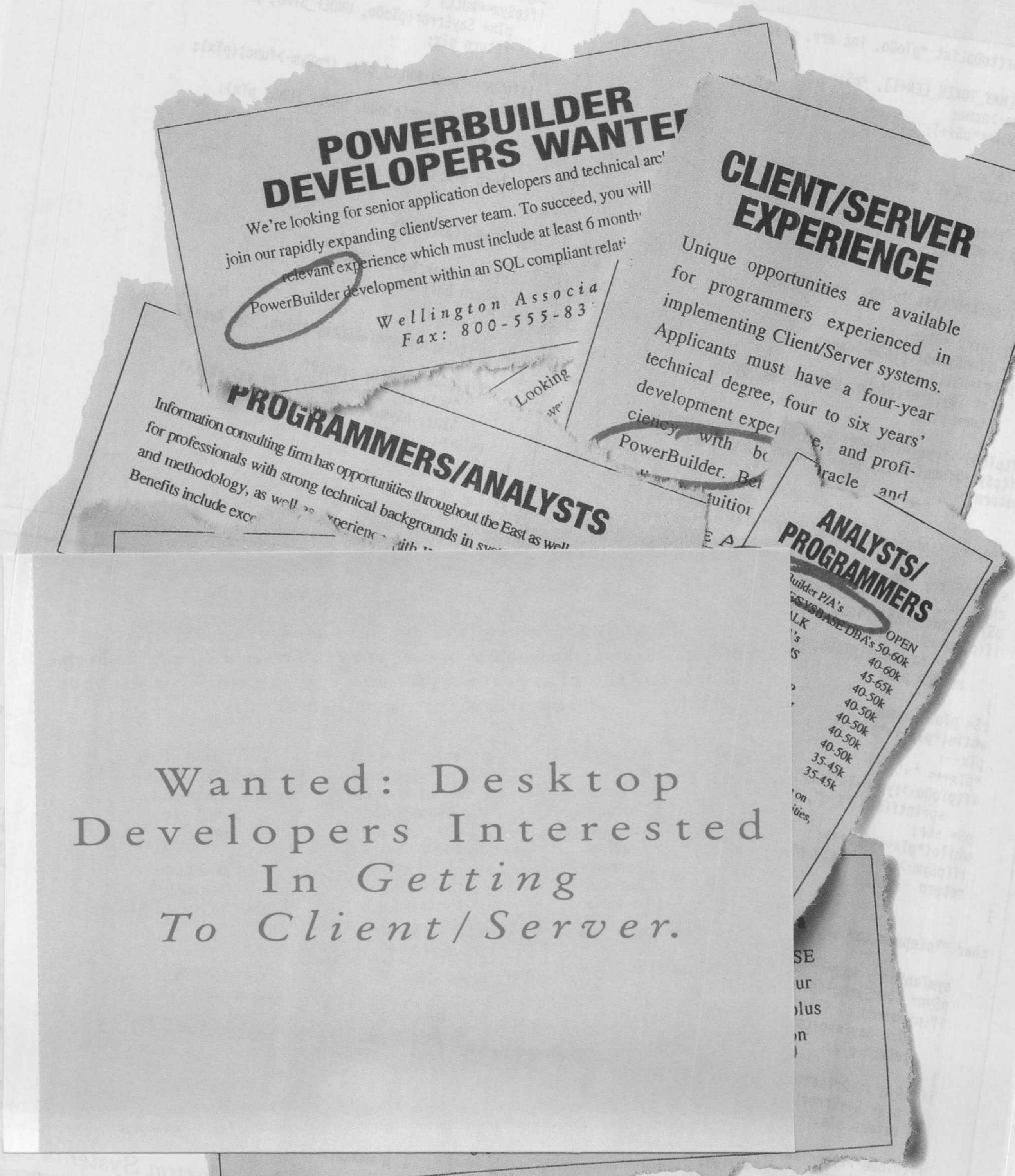
Final Thoughts

This symbolic data transfer scheme enabled us to implement a complete control system from scratch in about one programmer-month. When we started we had no clear picture of what the final result would be, so parameters were constantly added and removed as we tried different control strategies. By using the described method, we were able to respond quickly to these changes. This arrangement also made it easier to add auxiliary parameters for debugging. There are of course faster ways to transfer data, but the kinds of processes maintained by embedded controllers are often slow enough that a minor increase in response time isn't significant. □

Listing 2 *continued*

```
    {"reset"  , 0     , Reset, -1},
    {"status" , 35    , NULL , -1},
    {"temp"   , 16    , NULL , 20}
};

void PrintToDo(toDoList *toDo)
{
    while(toDo->command != EMPTY) {
        printf("\n %s %s '%s'",
            messList[toDo->command],
            messList[toDo->type], toDo->name);
        if(toDo->type==INTEGER)
            printf(" %d", toDo->value);
        toDo++;
    }
}


int SymCmp(symTabEntry *a, symTabEntry *b)
{
    return strcmp(a->name, b->name);
}

symTabEntry *FindSymbol(char *pName)
{
    symTabEntry dummy, *p;
    dummy.name= pName;
    p= (symTabEntry*) bsearch(&dummy, symTab,
        sizeof(symTab)/sizeof(symTabEntry),
        sizeof(symTabEntry),
        (int(*)(const void*, const void*))SymCmp);
    return p;
}

char *Reset(char *pC)
{
    printf("\nExecuting 'Reset'");
    return pC;
}

void DoCommands(toDoList *pToDo)
{
    char *txBuffer, *pTx;
    txBuffer= pTx= TxBuffer();
    *pTx= '\0';
    while(pToDo->command != EMPTY) {
    switch(pToDo->command) {
        case ERROR:
        case NAME_ERROR:
        case OP_ERROR:
        case VAL_ERROR:
        case END_ERROR:
        case POOL_ERROR:
        pTx= SayError(pToDo, pToDo->command, pTx);
        break;
        case ASSIGN:    pTx= Assign(pToDo, pTx);
                        break;
        case REQUEST:   pTx= Request(pToDo, pTx);
                        break;
        case TO_EEPROM: pTx= ToEeprom(pToDo, pTx);
                        break;
        case COMMAND:   pTx= RunCommand(pToDo, pTx);
                        break;
            default:          break;
        }
    ++pToDo;
    }
    printf("\ntxBuffer: '%s'\n", txBuffer);
}
```

```
char *SayError(toDoList *pToDo, int err, char *pC)
{
    char str[MAX_TOKEN_LEN+1], *pS;
    pS= pToDo->name;
    while(*pC++=*pS++);
    pC--;
    *pC++= '#';
    sprintf(str,"%-d", err);
    pS= str;
    while(*pC++= *pS++);
    return --pC;
}

char *Assign(toDoList *pToDo, char *pTx)
{
    symTabEntry *pSym;
    pSym= FindSymbol(pToDo->name);
    if(pSym==NULL) {
        pTx= SayError(pToDo, UNDEF_SYMB, pTx);
        return pTx;
    }
    if(pToDo->type==INTEGER) pSym->ival= pToDo->value;
    if(pSym->func!=NULL) pTx= (*pSym->func)(pTx);
    return pTx;
}

char *Request(toDoList *pToDo, char *pTx)
{
    symTabEntry *pSym;
    char *pS, str[MAX_TOKEN_LEN+1];
    pSym= FindSymbol(pToDo->name);
    if(pSym==NULL) {
        pTx= SayError(pToDo, UNDEF_SYMB, pTx);
        return pTx;
    }
    pS= pToDo->name;
    while(*pTx++=*pS++);
    pTx--;
    *pTx++= '=';
    if(pToDo->type==INTEGER)
        sprintf(str,"%-d", pSym->ival);
    pS= str;
    while(*pTx++=*pS++);
    if(pSym->func!=NULL) pTx= (*pSym->func)(pTx);
    return --pTx;
}

char *ToEeprom(toDoList *pToDo, char *pTx)
{
    symTabEntry *pSym;
    pSym= FindSymbol(pToDo->name);
    if(pSym==NULL) {
        pTx= SayError(pToDo, UNDEF_SYMB, pTx);
        return pTx;
    }
    if(pSym->eeOffset<0) {
        pTx= SayError(pToDo, NOT_EEPROM, pTx);
        return pTx;
    }
    if(pToDo->type==INTEGER) {
        pSym->ival= pToDo->value;
        WriteEeprom(pSym, INTEGER);
    }
    if(pSym->func!=NULL) pTx= (*pSym->func)(pTx);
    return pTx;
    }

char *RunCommand(toDoList *pToDo, char *pTx)
{
    symTabEntry *pSym;
    pSym= FindSymbol(pToDo->name);
    if(pSym==NULL) {
        pTx= SayError(pToDo, UNDEF_SYMB, pTx);
        return pTx;
    }
    if(pSym->func!=NULL) pTx= (*pSym->func)(pTx);
    else {
        pTx=SayError(pToDo, UNDEF_FUNC, pTx);
        return pTx;
    }
    return pTx;
}

char *TxBuffer(void)
{
    static char buffer[200];
    return buffer;
}

void WriteEeprom(symTabEntry *pSym, int type)
{
    if(type==INTEGER) printf(
        "\nTo EE, type: %d off: %d val: %d\n",
        type, pSym->eeOffset, pSym->ival);
    return;
}

/* End of File */
```



POWERBUILDER
DEVELOPERS WANTE
We're looking for senior application developers and technical arc
join our rapidly expanding client/server team. To succeed, you will
relevant experience which must include at least 6 month
PowerBuilder development within an SQL compliant relat
Wellington Associa
Fax: 800-555-83
CLIENT/SERVER
EXPERIENCE
Unique opportunities are available for programmers experienced in implementing Client/Server systems. Applicants must have a four-year technical degree, four to six years' development expe e, and profi- ciency with b PowerBuilder.
PROGRAMMERS/ANALYSTS
Information consulting firm has opportunities throughout the East as well for professionals with strong technical backgrounds in sys and methodology, as well as
ANALYSTS/
PROGRAMMERS
OPEN
50-60k
40-60k
45-65k
40-50k
40-50k
40-50k
40-50k
35-45k
35-45k
Wanted: Desktop
Developers Interested
In Getting
To Client/Server.

Credentials for sale: $249.

When i … lets your programs, as well as your

client/serv … inst any

of Power

by glanc

almost any trade journal. … n

both called it "Product … a

two Readers' Choice

Sources honored it wi … the

But PowerBuilder … ploy

when you peruse th

For there you can … you can

programmers with experie … e of $249.

proven client/server development tool.

So you'll be glad to know that PowerBuilder, previously available to developers with corporate IS needs and resources, is now available to desktop database developers as well.

Thanks to new PowerBuilder Desktop. A version of PowerBuilder created specifically for your standalone and networked desktop-class databases.

Similar to PowerBuilder Enterprise, this edition lets you create applications using a common object technology.

… orporate reseller or stop by CompUSA … -946-3500 and we'll tell you the nearest location and date of our one-day comprehensive client/server training class that includes your own copy of PowerBuilder Desktop for just $399.

After all, the price of becoming a client/server developer is a lot lower than the price of not becoming one.

For only $399, attend our one-day *Getting to Client/Server* training class and take home your own copy of PowerBuilder™ Desktop. Look for the city nearest you and call the toll-free number listed below for dates and details.

Atlanta	Indianapolis	Portland, OR
Boston	Los Angeles	Salt Lake City
Calgary	Minneapolis	San Francisco
Chicago	Nashville	San Jose
Cincinnati	New Orleans	Seattle
Dallas	New York	St. Louis
Denver	Orlando	Toronto
Detroit	Philadelphia	Vancouver
Houston	Pittsburgh	Washington, D.C.

1-800-946-3500

Powersoft™ GETTING TO CLIENT/SERVER digital™

Training classes co-sponsored by Digital Equipment Corporation and Powersoft.

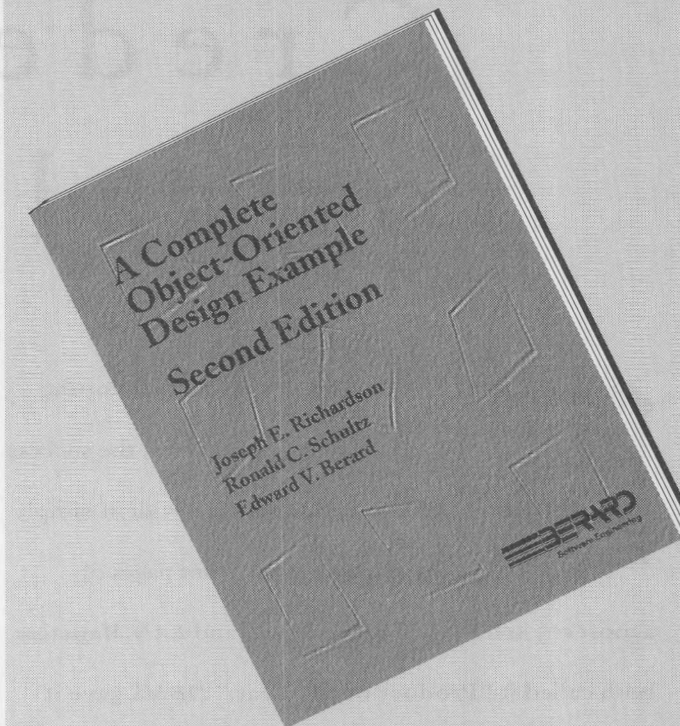
Powersoft™

Building on the power of people.

Powersoft Corporation, 70 Blanchard Road, Burlington, MA 01803
Powersoft Europe, Thames House, 1 Bell Street, Maidenhead, Berkshire, SL6 1BU, United Kingdom

"Don't Just Tell Me. . . *Show* Me."

"OK."



They say everybody loves an example. Since 1982, Berard Software personnel have trained thousands of people in object-oriented software engineering. Each client has had his or her own specific concerns, needs, and wants. But one thing they have all had in common is the desire to see a fully-worked object-oriented design example.

Our software engineers sought out an example problem that was straightforward but realistic. While the problem itself was important, the approach to solving it had to take center stage. The result? a *complete* object-oriented design example:

- The solution is complete — from statement of the problem to design documentation to delivered source code — nothing is left as "an exercise for the reader;"
- A significant amount of the thinking behind various design decisions, including discussions of design alternatives, is presented;
- The example shows solutions in two different programming languages, i.e., C++ and Smalltalk;
- The approach taken is generally programming-language independent, and easily adaptable to the object-oriented programming language of your choice.

This book, including all documentation and source code, contains over 250 clearly organized pages with informative graphics to aid the reader throughout. But we at Berard Software wanted to make your package even more complete. Available in either Macintosh or DOS formats and in both Smalltalk and C++ is the machine-readable source code used in the example... Now what could be more complete than that?

A Complete Object-Oriented Design Example is **Available Now.** Use the form below or contact Russ Hopler at (301) 417-9884.

☐ ***A Complete Object-Oriented Design Example*** (ISBN 1-881974-01-4): U.S. $50.00 per copy

☐ Machine-readable source code used in *OOD Example* (U.S. $15.00; Circle one: DOS MAC)

☐ Sales Tax (5%, Maryland Residents Only — U.S. $2.50 per book, $0.75 per diskette)

☐ Shipping and Handling: Add US: $5 per book, $1 per diskette (if shipped separately). Canada: US $10; Europe: US $20; Australia/Far East: U.S. $25

☐ VISA ☐ AMERICAN EXPRESS ☐ DISCOVER ☐ MASTERCARD

$_______ . ____ *Total Enclosed*

Name & Title:____________________

Address:____________________

City, State, Zip:____________________

Credit Card #:____________________ Exp. Date______

Signature____________________ Date______

Telephone: Area Code (______)____________________

BERARD Software Engineering

902 Wind River Lane, Suite 203, Gaithersburg, Maryland 20877
Phone: (301) 417-9884 • Fax: (301) 417-0021 • Internet: info@bse.com

ROMLDR, an Embedded System Program Locator

Charles B. Allison

MS-DOS software development tools such as C compilers and debuggers have become marvelously sophisticated and useful. They can also provide a cost-effective means for developing embedded systems. The purpose of this article is to introduce one of the aspects of using a high performance DOS-based C compiler for embedded systems, that of relocating code and data segments. I provide a program, *ROMLDR*, which can modify a program from the MS-DOS EXE format to a located binary file format.

ROMLDR's principle purpose is to adapt DOS-based C compiler output for use in EPROM-based embedded systems. Other uses include BIOS extensions, EPROM-based MS-DOS applications, and relocation of MS-DOS programs in PC memory, such as above the 640k MS-DOS memory limit. *ROMLDR* can also be used with EXE files generated by languages other than C.

ROMLDR was written using Borland C 3.1. It should be possible to use either Borland Turbo C or Microsoft C to make the *ROMLDR* program and to use for embedded programs. I have tested *ROMLDR* only with the Borland C 3.1 compiler.

Embedding DOS-Compiled Programs

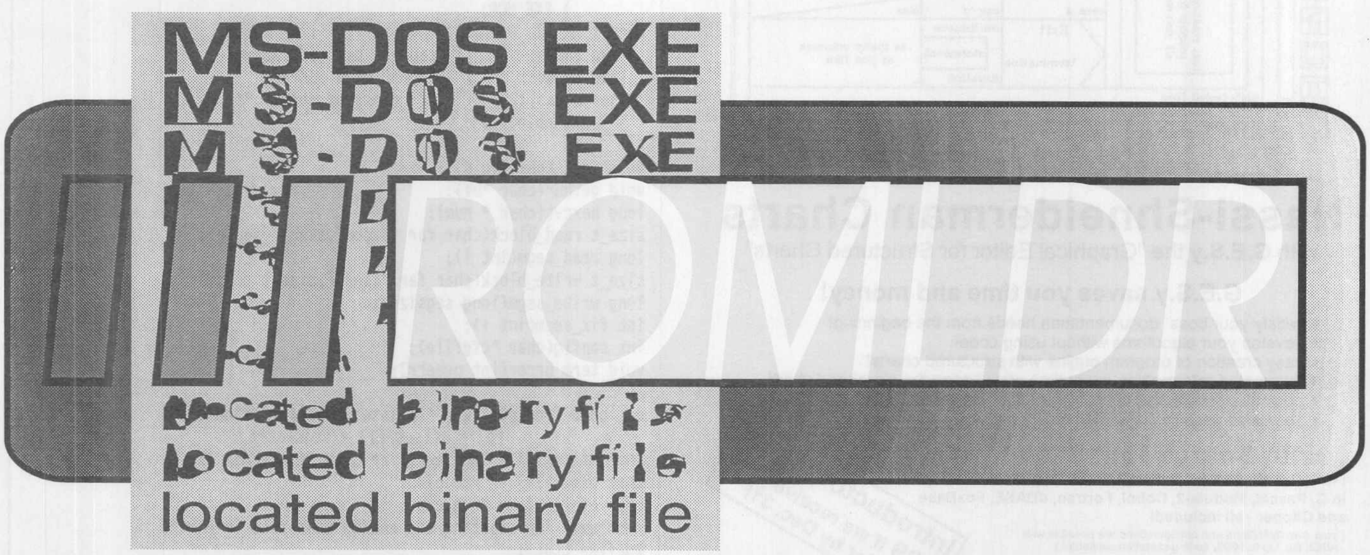
To use DOS-compiled programs in EPROM-based embedded systems, you must provide several additional components, as well as resolve some unique programming issues. A number of the required components, such as the startup code, depend on the compiler, target hardware, and application. (See the sidebar "Coding for Embedded Applications" for a brief discussion on embedded code requirements.)

Once you have attended to all these details, you can program, compile, and link the various program files into an MS-DOS EXE file. However, you can't just burn your EXE file into EPROM and go. You must explicitly perform a step that MS-DOS performs implicitly when it loads an EXE file.

MS-DOS modifies programs with the EXE extent when it loads them into memory. This modification, often referred to as a fix up (also known as the *locate* function), consists of modifying the program's segment values for the actual memory address where it is to run. By performing fix ups, DOS can load an executable almost anywhere in real-mode memory. (DOS can load small programs with the COM extent anywhere and run them without modification.)

DOS performs fix ups by adding the file's load-address segment value to all segment addresses stored in the code and data areas of the program.

Unlike DOS programs, most embedded systems programs reside in and execute from EPROM. Embedded system locators must perform fix ups prior to placing the program in EPROM and must take into account that variables will be located in RAM, through their initialized values for startup are still in EPROM.



Charles Allison has been working with microprocessor hardware and firmware in embedded systems since 1976. He has a Bachelor of Science degree in physics and a Master of Business Administration degree. Charles has a microprocessor consulting business, Allison Technical Services, where he has been developing embedded control and monitoring products for clients since 1984. Charles can be reached through CompuServe 71005,1502, his BBS/FAX line at (713)-777-4746 or his company, ATS, 8343 Carvel, Houston, TX 77036.

Locating for Embedded Systems

Before I present my program in detail, I want to outline the major parts of the location process. I will first describe the structure of a DOS EXE file, and how that structure is reflected in my code. Next, I will describe the location process.

EXE File Format

The EXE file consists of several sections, including a header, program code, data initialization values, and optional program debug information. Refer to structure *EXE_HDR* at the beginning of Listing 1 for the layout and definitions of the various parameters. The header section consists of several parameters which define the size of the file and the size of the header. Following these parameters is a section of fix-up *far* pointers.

Each of these pointers targets a location in the program code containing a segment address value that must be modified with the correct load address. These pointers are stored in standard 80x86 *segment:offset* format relative to the beginning of the code section. The pointers' segment values are derived from teh MAP file segment table by using the top four hexadecimal digits from the beginning address listed for each segment. (MAP files are generated by the compiler. MAP file segments consist of the top four hexadecimal digits of the beginning address.)

There are *num_reloc* fix-up pointers in the header section. These pointers begin at the offset *off_reloc* from the beginning of the header. (Note that fix-up pointers may not be sorted by address as they occur in the EXE file.) Following the header is the program's

Listing 1 *The EXE locator program*

```
/* ROMLDR.C EXE locator program
   written by: Charles B. Allison
   last change: 11-3-93 */

#include <sys\stat.h>
#include <io.h>
#include <dos.h>
#include <stdio.h>
#include <stdlib.h>
#include <alloc.h>
#include <conio.h>
#include <ctype.h>
#include <fcntl.h>
#include <string.h>
#define BC 1
/* BC is Borland c, else assume Microsoft */
typedef struct {
   unsigned sig;    /* signature = 4d5ah */
   unsigned lst_sec_lng;
        /*length of last sector in file modulo 512*/
   unsigned file_size;
   /* size of file in 512 byte pages includes hdr*/
   unsigned num_reloc;
               /* number of relocation items */
   unsigned hdr_siz;
           /* # of 16 byte paragraphs in header */
   unsigned min_ld_para;
          /* min # of paragraphs above load file */
   unsigned max_ld_para;
     /* max # of paragraphs requested by file */
   unsigned disp_stack_seg;
          /* rel displacement of stack segment */
   unsigned sp;
       /* contents of stack ptr on entry to prog */
   unsigned chksm;      /* check sum for file */
   unsigned ip;     /* beginning instruction ptr */
   unsigned rel_cs_seg; /* relative cs segment */
   unsigned off_reloc;
         /* offset to 1st relocation item typ. 1e */
   unsigned over_lay;          /* overlay number */
   unsigned rsrved;            /* ?? reserved ?? */
/* relocation item format is seg:off location
   relative to the beginning of the code section */
        } EXE_HDR;
struct MP_TBL {
  long addrs;         /* segment beg. address */
  long haddrs;      /* segment high addrs*/
  char class[12];         /* class of object */
  } maptable[120];

void sort_table(void);
void gethdr(char *bf);
long hexcvt(char * num);
size_t read_block(char far *segbuf,size_t segsz);
long read_segm(int i);
size_t write_block(char far *segbuf,size_t segsz);
long write_segm(long segsize);
int fix_segm(int i);
int config(char *cfgfile);
void term_error(int numerr);

unsigned (*ch_ptr)[2];/* pointer to translation table
                [0] = offset,[1] = segment*/
char mfile[14] = "rom.map"; /* dumy file names */
char bfile[14] = "rom.bin";
char efile[14] = "rom.exe";
/*columns for starting and ending addresses in MAP */
#define LCOL 1
#define HCOL 8
#ifdef BC
#define MAPCOL 41;
```

```
/*bc map file class column*/
#else
#define MAPCOL 45;
/*ms map file class column */
#endif
int class_loc = MAPCOL;
FILE *mapfile,*exefile,*binfile;
#define BUF_SIZE 60
char mapstring[BUF_SIZE];
long fsize; /*number of bytes in exe file */
int nsegs;  /* number of segments in map */
unsigned romsadr = 0xf000,ramsadr=0x40;
char header[10000];
EXE_HDR *filhdr = (EXE_HDR *)header;
char far *seg_buffer;
int next_fix = 0;
char ram_class[15] = "FAR_DATA";
unsigned ramdata; /* beginning ram segment*/
/* ************ main ************* */
int main(int argc,char *argv[])
{
int r_class_flag=1,i;
long tmp,ssize;

if((seg_buffer = (char far *) farmalloc(0x10000L))
          == NULL) term_error(0);
if(argc == 1) term_error(-1); /*any cfg file name? */
config(argv[1]);
i=0;
while (fgets(mapstring,BUF_SIZE,mapfile))
  {
/* process map file from mapstring input */
/* maptable[1] - n contains the segments -
class STACK should be last one */
/* ends with i having n+1 segments */
   if( (int)strlen(mapstring) > class_loc+1)
     {   /* get rid of \n at end of string */
      mapstring[(int)strlen(mapstring)-1]='\0';
      if((tmp = hexcvt(&mapstring[LCOL])) >= 0)
        {
     maptable[i].addrs = tmp;
     maptable[i].haddrs=hexcvt(&mapstring[HCOL]);
             &mapstring[class_loc]);
       strcpy(maptable[i].class,
               &mapstring[class_loc]);
     if(r_class_flag)
     if(strcmp(&mapstring[class_loc],ram_class)==0)
       { /*set it to first class occurance*/
        ramdata = (maptable[i].addrs) >>4;
        r_class_flag = 0;
       }
     printf("\n Segment %4.4lx  Class  %s",
     maptable[i].addrs/16,maptable[i].class);
     i++;
       }/* end - if hexcvt  */
     } /* end if strlen */
   if(i>=119) break;  /* error too many segments */
  } /* end while */
if(feof(mapfile))
     printf("\nend of file\n");
  else
     printf("\nerror reading map file\n");
nsegs = i-1; /* number of segments  [1 to nsegs] */
gethdr(header); /* read in the exe header info */
/* size of object section of file */
fsize = (long) ((512L * (filhdr->file_size-1)) +
     filhdr->lst_sec_lng - 16L * filhdr->hdr_siz);
printf("\nStartup Address %4.4x:%4.4x\n",romsadr+
             filhdr->rel_cs_seg,filhdr->ip);
printf("Rom Size %lx\n",fsize);
/* process the exe file header - sort fix ups */
sort_table();
/* read in exe file by segment
do fixups from map table and
write it to output file */
for(i=0;i < nsegs;i++)
    {
     if((ssize = read_segm(i)) > 0L )
       { /* ignore 0 length segments */
     fix_segm(i);
     write_segm(ssize );
       }
    }
/* done - end the program */
farfree(seg_buffer);
fcloseall();
return 0;
}
/* ***************** */
/* qsort routine for far pointers */
int cmp_ptr(const void *a, const void *b)
{
long vala,valb;
vala=((long)((unsigned *)a)[0])+
          (((unsigned *)a)[1]<<4);
valb=((long)((unsigned *)b)[0])+
          (((unsigned *)b)[1]<<4);
vala -= valb;
if(vala < 0) return -1;
if(vala > 0) return 1;
return 0;
}
```

code section. This section consists of one or more separate segments, the number and type of which depend on the program and its memory model. Following the code is the initialized data section. Then comes the uninitialized data section, and finally the stack.

The Location Process

Once it has loaded a program into memory, the MS-DOS loader adds the code section's segment address to the segment value stored in each location requiring a fix up. The loader finds these locations by dereferencing each fix-up pointer in the header. MS-DOS sets the CPU's stack registers to `disp_stack_seg:sp` and calls the program at address `rel_cs_seg:ip`. (Note: For the sake of illustration, I use `disp_stack_seg`, `sp`, `rel_cs_seg`, and `ip` to represent values stored at specific offsets within the EXE header. By referring to fields of the same name in my `struct`, `EXE_HDR`, you can see where these values are stored in the header.) MS-DOS also provides some environment and header information to the loaded program through register contents.

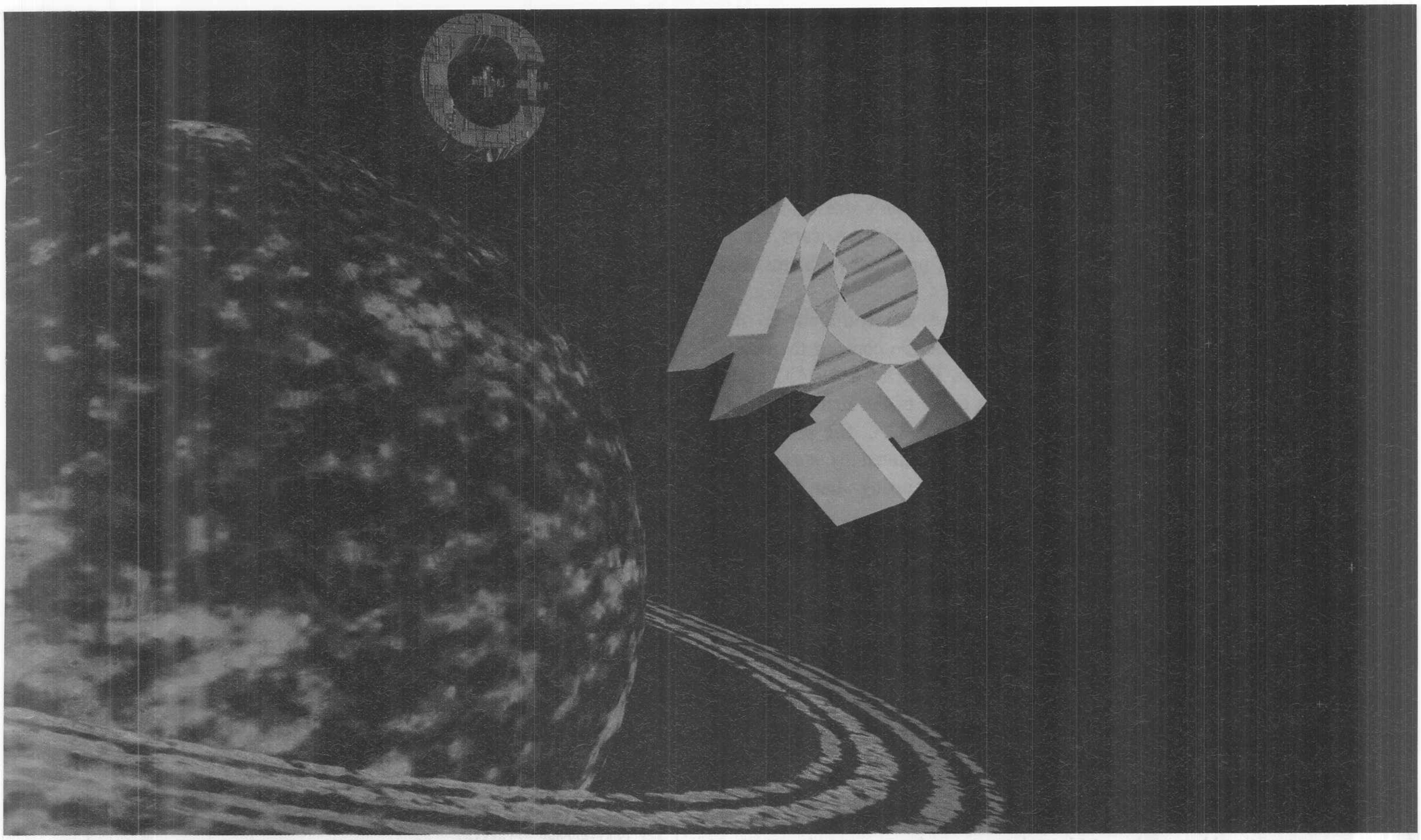
Most, but not quite all of the information necessary to generate rommable absolute binary files already exists in the EXE file. The rest of the information must come from the segment data in the compiler's MAP file and from configuration information provided by the user in a loader configuration file.

Program Description

ROMLDR uses the linked EXE file and its MAP file to create a binary file that can be programmed into EPROMs.

Listing 1 *continued*

```
/* ------ sort_table -------- */
/* sort header table */
void sort_table(void)
{
 qsort((void *)&header[filhdr->off_reloc],
        filhdr->num_reloc,4,cmp_ptr);
}
/* ------- read_block -------- */
size_t read_block(char far *segbuf,size_t segsz)
{
if(fread(segbuf,1,segsz,exefile) != segsz)
     term_error(-7);
return segsz;
}
/* ------- read_segm --------- */
long read_segm(int i)
{
long segsize;
segsize = maptable[i].haddrs - maptable[i].addrs;
if(!segsize) return 0;
segsize += maptable[i+1].addrs-(maptable[i].haddrs);
if(segsize <= 0x8000)
  { read_block(seg_buffer,(size_t)segsize);
  } else {
   read_block(seg_buffer,0x8000);
   read_block((&seg_buffer[0x8000]),
          (size_t)(segsize-0x8000));
  }
return segsize;
}
/* --------- write_block ---------- */
size_t write_block(char far *segbuf,size_t segsz)
{
if(fwrite(segbuf,1,segsz,binfile) != segsz)
     term_error(-8);
return segsz;
}
/* ------- write_segm ---------- */
long write_segm(long segsize)
{
if(!segsize) return 0;
if(segsize <= 0x8000)
  { write_block(seg_buffer,segsize);
  } else {
   write_block(seg_buffer,0x8000);
   write_block((&seg_buffer[0x8000]),
          (size_t)(segsize-0x8000));
  }
return segsize;
}
/* ------ fix_segm ------- */
int fix_segm(int i)
{
unsigned tmp,cseg,fixup;
unsigned far * fixptr;
cseg = (unsigned)(maptable[i].addrs/16L);
while(next_fix < filhdr->num_reloc)
  {
   if(ch_ptr[next_fix][1] > cseg) break;
   tmp = ch_ptr[next_fix][0]; /*offset into buffer*/
   fixptr = (unsigned far *) &seg_buffer[tmp];
   fixup = *fixptr;
/* modify segment fixup according to type */
   if(fixup >= ramdata)
     {/* modify for ram */
      fixup -= ramdata;
      fixup += ramsadr;
     }
     else
     {/* handle as rom */
      fixup += romsadr;
     }
```



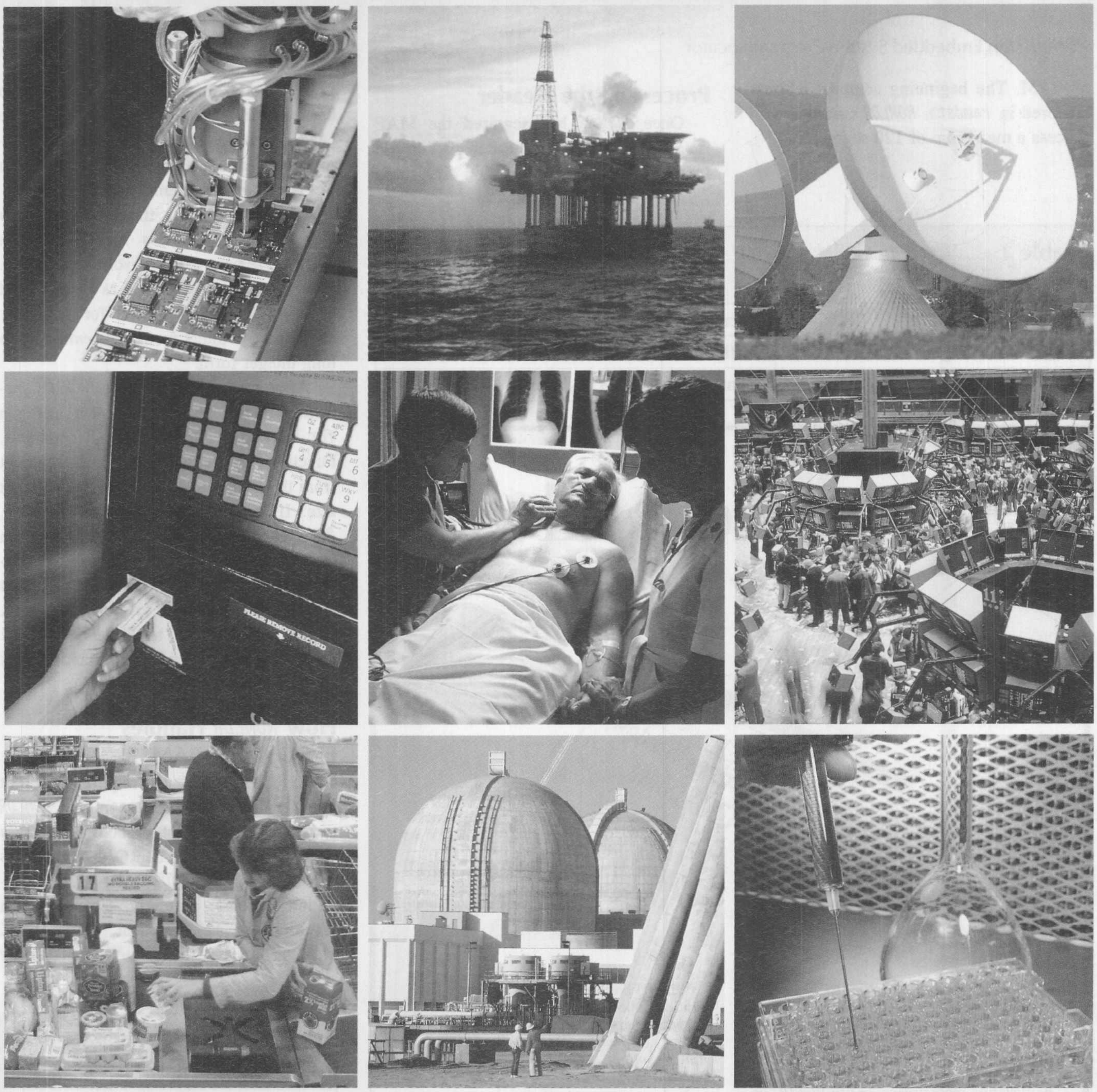
within the Borland IDE, I had to reduce the buffer's size significantly due to memory constraints.) A simple error routine, *term_error*, generates error messages for a variety of potential problems, and provides for program termination.

After allocating a buffer, *ROMLDR* reads the configuration file (CFG) specified on the command line. This file contains the names for the EXE, MAP, and BIN output files, EPROM and RAM hexadecimal load addresses, and the class name of the first RAM segment. Table 1 shows the CFG file format. CFG file parameters must be located on separate lines and separated by spaces. On each line, *ROMLDR* ignores any characters occurring after the list of required parameters.

Reading the MAP File

ROMLDR executes a *while* loop to read and process lines of text from the MAP file. (The MAP file used with *ROMLDR* should be the short version, which contains only the segment table.) *ROMLDR* extracts memory allocation class names, plus their starting and ending addresses, and stores them in an array of structures called *maptable*. *ROMLDR* performs a simple length check using configuration variable *class_loc* to determine if the current line contains segment information. *ROMLDR* expects the line to be in a fixed column format, with the class name occurring at offset *class_loc*. *ROMLDR* converts address values to long integers, and compares class names with *ram_class*, a configuration variable used to define the beginning

```
   *fixptr = fixup;
   next_fix++;
  } /*end while */
return 0 ;
}
/* -------- hexcvt ------- */
/* do hex digits to unsigned long */
long hexcvt(char * num)
{
char *term;
long value;
value = strtoul(num,&term,16);
return value;
}
/* ------- gethdr -------- */
void gethdr(char *buf )
{
int i,j=32; /*index counter */
     if(fread(&buf[0],1,32,exefile) < 32)
     term_error(-6);
/* have filhdr contents so get size of full header */
if(fread(&buf[j],16,filhdr->hdr_siz-2,exefile)
        < filhdr->hdr_siz-2) term_error(-6);
(unsigned *)ch_ptr =
      (unsigned *)(&buf[filhdr->off_reloc]);
/* get address of relocation table - ch_ptr [n][m]
 m - 0 offset, 1 - seg, n relocation # */
}
/*----------- config -------------*/
/* get configuration data */
int config(char *cfgfile)
{
FILE *cfg;
char buf[80];
if((cfg = fopen(cfgfile,"r"))==NULL) term_error(-1);
if(fgets(buf,80,cfg) == NULL) term_error(-2);
if(sscanf(buf,"%s %s %s",&mfile,
           &efile, &bfile) != 3) term_error(-2);
/* Now try to open input file 1 */
if((mapfile=fopen(mfile,"r"))==NULL)  term_error(-3);
if((exefile=fopen(efile,"rb"))==NULL) term_error(-4);
if((binfile=fopen(bfile,"wb"))==NULL) term_error(-5);
if(fgets(buf,80,cfg) == NULL) term_error(-7);
if(sscanf(buf,"%4x %4x",&romsadr,
           &ramsadr) != 2) term_error(-7);
if(fgets(buf,80,cfg) == NULL) term_error(-7);
if(sscanf(buf,"%s",&ram_class) != 1) term_error(-7);
return 0;
}
/* error handler */
char *errlist[10] = {
 "Memory Allocation Error",
 "No configuration file, USAGE:romldr cfgfile.cfg",
 "Configuration file error - File names",  //-2
 "Map File open error",                     //-3
 "Exe File open error",                     //-4
 "Bin File open error",                     //-5
 "Error reading header",         //-6
 "Error reading exe file",            //-7
 "Error writing bin file",       //-8
 " "
     };
void term_error(int errnum)
{
errnum = abs(errnum);
if(errnum >= 9) exit(-1);
printf("%s\n",errlist[errnum]);
farfree(seg_buffer);
exit(errnum);
}

/* End of File */
```



of RAM. The beginning segment address is stored in *ramdata*. *ROMLDR* currently will process a maximum of 120 segments.

Processing the Header

Once *ROMLDR* has acquired the MAP file, it reads the EXE header portion via function *gethdr*. This function first reads in 32 bytes of the header to determine the header's size and then loads the rest of the header. This function stores header information in an array named *header* which can contain a maximum of 10,000 bytes.

ROMLDR then sorts the fix-up pointers into ascending address order. Function *sort_table* uses *qsort* to sort the pointers. Function *cmp_ptr*, supplied as an argument to *qsort*, compares values for *qsort* by converting pointers from *segment:offset* to long integer form.

After sorting the pointers, *ROMLDR* performs fix ups on each segment, using a *for* loop to iterate through all segments. Function *read_segm* reads each segment from the EXE file and returns the segment size. If the segment length is non-zero, *ROMLDR* calls function *fix_segm* to run through any fix ups needed for the segment and then calls *write_segm* to output the processed segment to the BIN file. (A logical enhancement to *ROMLDR* would be to output the segments in a standard hex format, such as Intel hex format.)

How *ROMLDR* Handles EPROM and RAM

EPROM segments require different modifications than RAM segments. *ROMLDR* treats all segments at or below the class named *ENDCODE* as EPROM and treats those above *ENDCODE* as RAM. The location process currently terminates on reaching the last segment, the STACK class. (The BIN file, however, needs only

Table 1 *CFG file format*

Mapfile Exefile Binfile	// filenames with no path
ROM_Address RAM_address	// 4 digit hex addresses [0...9,a...f]
Ram_Class	// name for first RAM segment

Listing 2 *Sample program that produces segment classes*

```
DEMO.C
/* Test Program for Rom Loader */
/* Large model with some far data*/
#include <conio.h>
#include <dos.h>

char msg[15] = "Hello World\n\r";
int locint;
int directvideo=1; /*BC direct to hw*/
int far test;
int far test2=0x55aa;
int far * tptr = &test;

void main(void)
{
int far * ptr2 = &test;
test = 0x1111;
locint = test+1;
 cputs(msg);
}
/* End of File */
```

to contain code and data segments up to the last initialized data value.)

The *ENDCODE* class name is special for another reason. ROM based systems typically must transfer initialized data from EPROM to RAM. Therefore, *ROMLDR* will modify all references to data segments to refer to the RAM locations and not to the initial values located in the EPROM. (The location for the initial values must be used in the startup code so that they can be transferred to RAM.) Segment *ENDCODE* is used for this purpose. I make the *ENDCODE* segment's length less than 16 bytes, locate it on a paragraph boundary, and ensure that the beginning data segment is also aligned by paragraph. As a result, the beginning ROM location for initialized data becomes *ENDCODE*+1. Since *ENDCODE*'s address is less than the beginning of the RAM segment, it will refer to the ROM address just below the initialized data values.

ROMLDR modifies EPROM data by adding the configuration file's EPROM segment address, stored in *romsadr*, to the code's existing segment value. (A more sophisticated version of the program could offer the option of several user-defined addresses and the names of the classes that would reside in each.)

ROMLDR modifies RAM segments by first subtracting out the value of the first RAM segment and then adding the configuration file's RAM segment location value. This method allows the RAM locations to begin at the configuration-defined starting value. The subtraction was not necessary for code segments since they began with a zero segment value.

Example Code

Listing 2 is *DEMO.C*, a typical "Hello World" program with some added items to provide examples of values for several segment classes. Listing 3, *DEMO.MAP*, is the map file generated for *DEMO.C* using the example startup code in Listing 4 instead

Coding for Embedded Applications

Writing embedded systems applications requires special efforts on the part of the programmer, because of how these applications differ from non-embedded applications. First, an embedded program that crashes can cause damage or injury, while a non-embedded program (e.g. a word processor) may cause only a certain amount of user frustration. Embedded systems must handle the conceivable problems in stride and effectively recover from the inconceivable without help from users.

Second, there are several special aspects to embedded code. Many embedded systems run standalone programs without the support of complete operating systems such as MS-DOS, so these programs must take control of relevant interrupt vectors (including error conditions such as divide by 0 and the Non-Maskable Interrupt). For these standalone programs, both the hardware and the program may require setup code. Programs compiled to run under MS-DOS contain startup and termination code to accept control from and return control to the operating system. Standard library functions that don't access MS-DOS under normal conditions may contain error-handling code that does access MS-DOS or that would terminate the program in an unacceptable fashion within an embedded system. In addition, some programs may attempt to access non-disk MS-DOS functions, such as those used to modify interrupt vectors. If you port such programs to an embedded system, you must provide code to perform equivalent functions within the embedded system operating environment. An embedded program must start (or restart) in a known state. Since the program cannot obtain state information from a command line, it must find initial state data in EPROM. □

```
DEMO.MAP
 Start  Stop   Length Name                 Class

 00000H 00000H 00000H ROMSTART_BEG         CODE
 00000H 00E8FH 00E90H _TEXT                CODE
 00E90H 00EC9H 0003AH DEMO_TEXT            CODE
 00ED0H 00ED5H 00006H ENDCODE              ENDCODE
 00EE0H 00EE0H 00000H IDATA_BEG            IDATA_BEG
 00EE0H 00EE0H 00000H _FARDATA             FAR_DATA
 00EE0H 00EE3H 00004H DEMO5_DATA           FAR_DATA
 00EF0H 00FB9H 000CAH _DATA                DATA
 00FBAH 00FBBH 00002H _CVTSEG              DATA
 00FBCH 00FC1H 00006H _SCNSEG              DATA
 00FC2H 00FC2H 00000H CONST                CONST
 00FC2H 00FC7H 00006H _INIT_               INITDATA
 00FC8H 00FC8H 00000H _INITEND_            INITDATA
 00FC8H 00FC8H 00000H _EXIT_               EXITDATA
 00FC8H 00FC8H 00000H _EXITEND_            EXITDATA
 00FD0H 00FD0H 00000H IDATA_END            IDATA_END
 00FD0H 00FD0H 00000H UDATA_BEG            UDATA_BEG
 00FD0H 00FD1H 00002H _BSS                 BSS
 00FD2H 00FD2H 00000H _BSSEND              BSSEND
 00FE0H 02FDFH 02000H STACK                STACK
 02FE0H 02FE0H 00000H UDATA_END            UDATA_END

Program entry point at 0000:0000
```

Listing 4 *An example of startup code*

```
    NAME    ROMSTART_TEXT
;
; example startup code for
; imbedded systems use
;
; segment classes
; High addrs (rom)
; 'BOOT'
; ""
; ""
; 'CODE'          _TEXT segment
;
; ram
;
; 'STACK'    UDATA_END segment
; 'BSS'      IDATA_END and UDATA_BEG segments
; 'CONST'
; 'DATA'     IDATA_BEG segment
;
; Rename object file output to c0x.obj
; where x = S,C,M,L, or H
; and locate in project subdirectory
; Memory model selection set to 1 all others 0
;
SMALLM   EQU 0
COMPACTM EQU 0
MEDIUMM  EQU 0
LARGEM   EQU 1
HUGEM    EQU 0

STACK_SIZE  EQU 1000H        ;set desired stack size
__acrtused  equ 1            ;satisfy external reference

    PUBLIC  __acrtused

DGROUP GROUP IDATA_BEG, _DATA, CONST, IDATA_END,\
        UDATA_BEG, _BSS, STACK, UDATA_END

; this segment marks beginning of rom code
ROMSTART_BEG SEGMENT BYTE 'CODE'
ROMSTART_BEG ENDS

IF SMALLM OR COMPACTM
_TEXT SEGMENT BYTE PUBLIC 'CODE'
    EXTRN    _main:NEAR      ;main program
ASSUME CS:_TEXT

ENDIF
IF MEDIUMM OR LARGEM OR HUGEM
    EXTRN   _main:FAR  ;main c program
_TEXT SEGMENT BYTE PUBLIC 'CODE'
    ASSUME CS:_TEXT
ENDIF

    ASSUME DS:DGROUP, SS:DGROUP
    PUBLIC start

start   PROC  NEAR
    cli
    cld
;******************************************
;
; do hardware initialization and ram check
;
;******************************************

    PUBLIC  init_ram

init_ram:
;*********
; transfer initialize data from rom to ram
;
    MOV BX, SEG IDATA_BEG
    MOV AX, SEG IDATA_END     ;data to init.
    sub ax,bx
    mov cl,3
    shl ax,cl
    mov cx,ax
    jcxz    no_init_data

;address of frame # in rom
    mov ax, seg ENDCODE    ;needed for jbromldr
    inc ax            ;ram init values begin at
    mov ds,ax       ;segment ENDCODE + 1
    mov si,0
;address of frame # in ram
    mov ax, seg IDATA_BEG
    mov es,ax
    mov di,0
; initialize data and const segments
rep movsw    ;word transfer
no_init_data:
    mov bx, seg UDATA_BEG   ;clear bss data
    mov ax, seg UDATA_END
    sub ax, bx
    mov cl,3
    shl ax,cl
    mov cx,ax
    jcxz no_zerodata
    mov es,bx
    mov di,0
    mov ax,0
rep stosw
    PUBLIC  no_zerodata
no_zerodata:
    mov ax,DGROUP  ; set up stack
    mov ds,ax
    mov ss,ax
    mov sp,OFFSET DGROUP:STACK_TOP
```

of the standard Borland startup code. Note that the `_INIT_` segment contains some values which are addresses of library initialization routines that should be called in order of priority. The example startup code does not yet include this section or the interrupt vector initialization section. Examples of these can be found in your compiler's startup code. The sidebar "Startup Code for Embedded Systems" provides a discussion of startup code requirements.

Startup Code for Embedded Systems

Startup code consists of code to setup and to terminate an application program. Startup code is typically written in assembly language and the source code is sometimes provided with the C compiler. Replacement libraries often include replacement startup code that can be used when the normal C compiler library functions are not used.

Startup code for EPROM-based systems must provide additional functionality which depends on the specifics of the system.

Embedded system startup code usually performs the following steps:

1. Establish order of segment classes.
2. Set up the program stack.
3. Transfer initialized values to RAM from EPROM.
4. Zero uninitialized RAM values.
5. Set up error interrupt vectors.
6. Call necessary library initialization routines.
7. Call the application.

The startup code must also provide the following components:

8. Error shut-down code to terminate or restart.
9. Exit shut-down code to terminate or restart.
10. Any error and miscellaneous routines.
11. Initialization of application before calling main function.
12. A reset vector for standalone applications.

There are two approaches to creating a custom startup module. You can start with the original library or compiler code and modify it to handle the added embedded requirements, or you can start with a minimal embedded system startup module and extend it as required.

Custom startup code may not provide all features described in a compiler's documentation. Environment, `argv` and `argc`, and even common option variables may not be implemented. For example, Borland C allows you to set stack size by initializing a far variable, `_stklen`. This variable is created by the Borland startup code and may be replaced in custom startup code by a simple stack-size definition.

Startup code defines segments and segment classes and their order. While compilers often allow these names to be changed for modules, the compiled libraries are still expecting certain module names to exist. Warnings abound over changing the basic segment order so extreme care should be used if that appears to be necessary. The addition of segments and classes is much less critical. As shown in Listing 4, you can even add them virtually to make the MAP more descriptive.

Listing 4 is a simple example of startup code. I provide it as a template rather than a complete example since some portions are compiler dependent. You may still need to add several code sections for an application. Refer to your compiler's startup code module for specific details. □

ROMLDR Versus Commercial Products

ROMLDR has several shortcomings when compared to commercial locator packages. When you use *ROMLDR* you must provide startup code for your application; commercial products usually provide the basic startup code required as well as code solutions for a variety of problems which must be overcome in various embedded configurations. *ROMLDR* does not provide debugging support, but commercial products usually provide some capabilities for the debugging of application programs. Finally, vendors of commercial locator packages often provide technical support; when you use a non-commercial package such as *ROMLDR* you must solve all problems on your own.

Conclusions

While *ROMLDR* is intended primarily as a learning tool and an introduction to embedded systems, it can prove useful for some low-end applications. *ROMLDR* should be able to handle straightforward applications where there is one EPROM and one RAM memory space. It can easily be modified for more complex configurations, especially those which have specific fixed requirements.

Embedded systems often monitor and control equipment other than normal computer peripherals. Embedded systems programmers must be extra cautious, since bugs in their programs can place property and lives at risk. In this situation, there is no substitute for understanding both the application and the tools. Understanding how *ROMLDR* works may give you insight into how more complex systems operate. □

Listing 4 *continued*

```
;********************************************
; add code to:
;  1) initialize INITDATA Functions (see c0.asm)
;  2) capture interrupt vectors 0-4
;********************************************
    sti ;enable interrupts
    call _main  ;enter main program
;********************************************
; add code to:
;  1) shut down EXITDATA Functions
;  2) handle shutdown errors
;  3) prepare to restart
;********************************************
    jmp start
start ENDP
_abort          PROC    DIST
        PUBLIC _abort
;handle error abort
    jmp start
_abort ENDP
IF SMALLM OR COMPACTM
_TEXT ENDS
ENDIF
IF MEDIUMM OR LARGEM OR HUGEM
_TEXT ENDS
ENDIF

; segment marks end of rom code
;make it non zero, length < 16 bytes
ENDCODE SEGMENT PARA PUBLIC 'ENDCODE'
        db  "ENDROM"   ;seg ENDCODE+1 = begin ram
ENDCODE ENDS
;********************************

;beginning of dgroup and initialized data in ram

IDATA_BEG    SEGMENT PARA PUBLIC 'IDATA_BEG'
IDATA_BEG    ENDS

_FARDATA     SEGMENT PARA PUBLIC 'FAR_DATA'
_FARDATA     ENDS

_DATA    SEGMENT PARA PUBLIC 'DATA'
_DATA    ENDS

_CVTSEG SEGMENT WORD PUBLIC 'DATA'
 PUBLIC __RealCvtVector
__RealCvtVector label word
_CVTSEG ENDS
_SCNSEG SEGMENT WORD PUBLIC 'DATA'
_SCNSEG ENDS
CONST    SEGMENT WORD PUBLIC 'CONST'
CONST    ENDS

_INIT_   SEGMENT WORD PUBLIC 'INITDATA'
_INIT_   ENDS
_INITEND_ SEGMENT WORD PUBLIC 'INITDATA'
_INITEND_ ENDS

_EXIT_   SEGMENT WORD PUBLIC 'EXITDATA'
_EXIT_   ENDS

_EXITEND_ SEGMENT WORD PUBLIC 'EXITDATA'
_EXITEND_ ENDS

IDATA_END SEGMENT PARA PUBLIC 'IDATA_END'
IDATA_END ENDS

; end of initialized data

UDATA_BEG SEGMENT WORD PUBLIC 'UDATA_BEG'
UDATA_BEG ENDS

_BSSSEGMENT WORD PUBLIC 'BSS'
_BSSENDS
_BSSEND SEGMENT BYTE PUBLIC 'BSSEND'
_BSSEND ENDS

STACK    SEGMENT PARA STACK 'STACK'
   DW  STACK_SIZE DUP (?)

STACK_TOP    LABEL WORD
STACK    ENDS

; end of initialized segment in ram
UDATA_END SEGMENT WORD PUBLIC 'UDATA_END'
UDATA_END    ENDS
; bootstrap address for powerup reset
; far jump to program beginning
; may have to be manually placed in EPROM
;BOOTSTRAP    SEGMENT AT 0FFFFH
;   JMP FAR PTR start
;
;BOOTSTRAP ENDS
   end start

; End of File
```

A Fuzzy-Logic Torque Servo

Jack J. McCauley

Background

The developer of a control system desires a well-behaved system that is stable throughout the operating spectrum. In the process of designing and debugging the controller, operating regions that exhibit oscillatory or unstable operation are avoided. Non-linearities are typically modeled using a series of discrete equations developed for the system.

A PID or Proportional Integral Differential controller is an example of a closed-loop system. Implemented discretely, it would compute at z intervals:

$$T(z) = T(z-1) + K_k * (E(z) - E(z-1)) \\ + K_i * E(z) + K_d * E(z-2) * (1 + E(z-1))$$

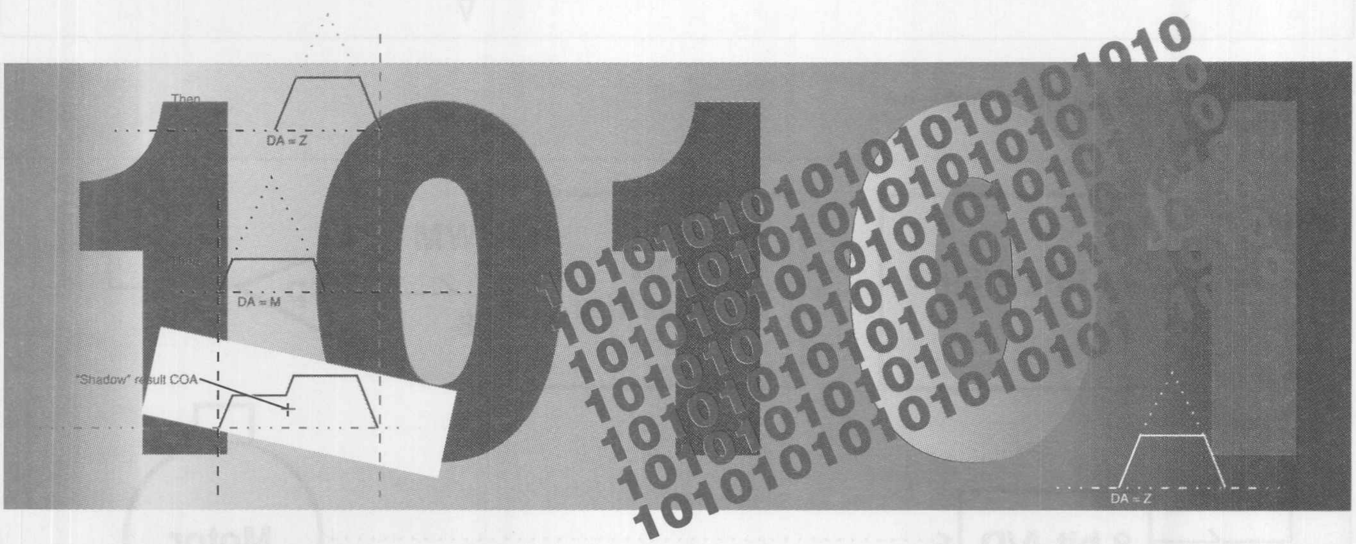
In this linear example, the z sampled periods for the controller represent discrete time samples and K_k, K_i, and K_d are constants. A non-linear system designer might attempt to modify K_k, K_i, and K_d as a function of input $E(z)$. This of course would require $K_k(z)$, $K_i(z)$, and $K_d(z)$ (and possibly $K_k(z-1, z-2, \ldots z-n)$ etc). The designer would compute stability and phase margin in a continuous system and convert these to the discrete world using a Discrete Transform.

After the analysis the designer would proceed to code $T(z)$ into assembler or C and port it to a target. This article describes how to implement a simple *fuzzy-logic* based servo controller in the C programming language. C language portability allows the controller to run in either a micro-controller based environment or on a PC.

Escaping Brittleness

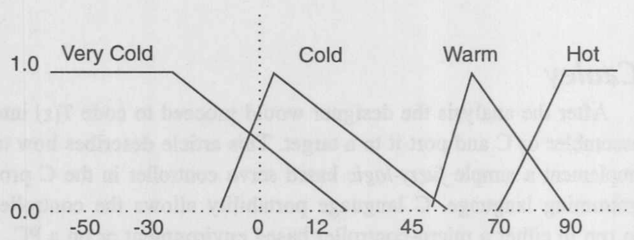
Brittleness is the bane of the control-system designer. A brittle system is one which "breaks" easily. For example, in the coding of $T(z)$, we defined the output $T(z)$ to be an eight-bit `unsigned char` that follows the eight-bit radix of our A/D converter. Suppose that several of the terms of $T(z)$ were discreetly nine or ten bits. The result could be truncated and thus produce incorrect output when $T(z)$ was cast to an `unsigned char`. We must check overflow after every operation of $T(z)$ and perform corrective logical operations.

Besides the implementation issues, PID and PI suffer from some serious real-world problems. In controls, non-linearities are the rule. Factors such as friction and temperature affect the behavior of systems. What appears to be stable under one set of conditions yields poor performance under another.



Since receiving a BSEE from UC Berkeley, Jack J. McCauley has been working as a Software Engineering Consultant. His specialty is real-time systems with an emphasis on servo controls and signal processing. He can be reached at (510) 531-1581.

Figure 1 *Fuzzy set for temperature*



There are techniques for dealing with changes. One possibility is to *sliding-mode* modify the PI gain parameters. Experience with this approach has shown that it works very well so long as the inputs are bounded properly. Current thinking, however, indicates that the amount of time invested in developing this approach will not be extracted in performance. What most people do to deal with non-linearities is to add a bunch of testing and branching code to deal with the caveats. In most PID, PI closed-loop systems, it ends up that the majority of the code is dedicated to dealing with these anomalies.

Fuzzy Logic

Fuzzy logic holds promise as a means of handling control-system non-linearities. It provides a unique way of looking at control

Figure 2 *Feedback configuration of a typical torque servo*

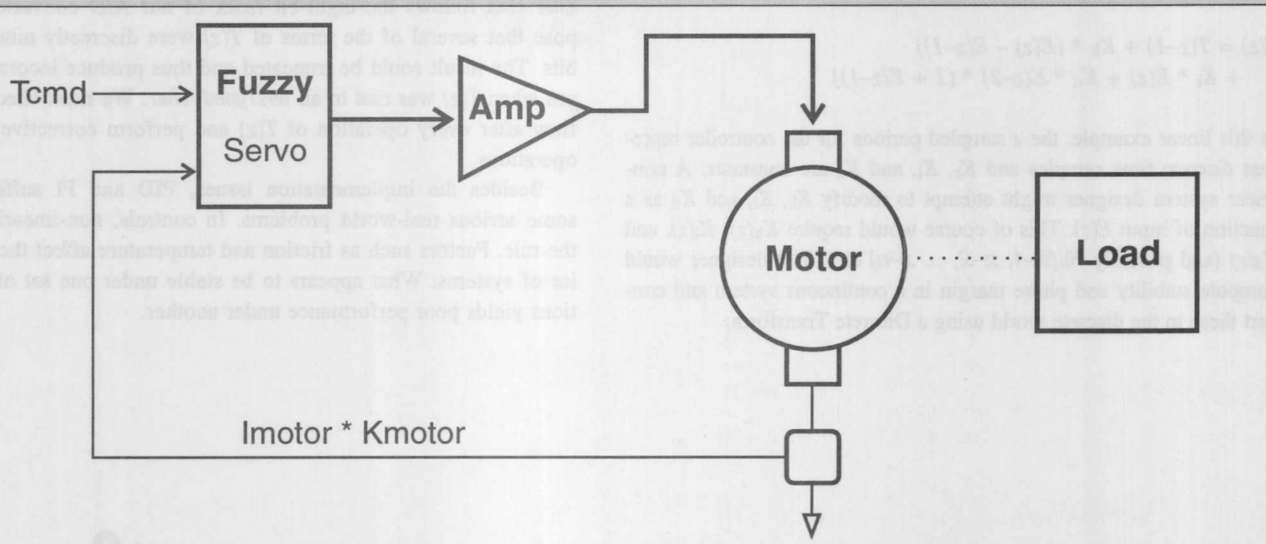
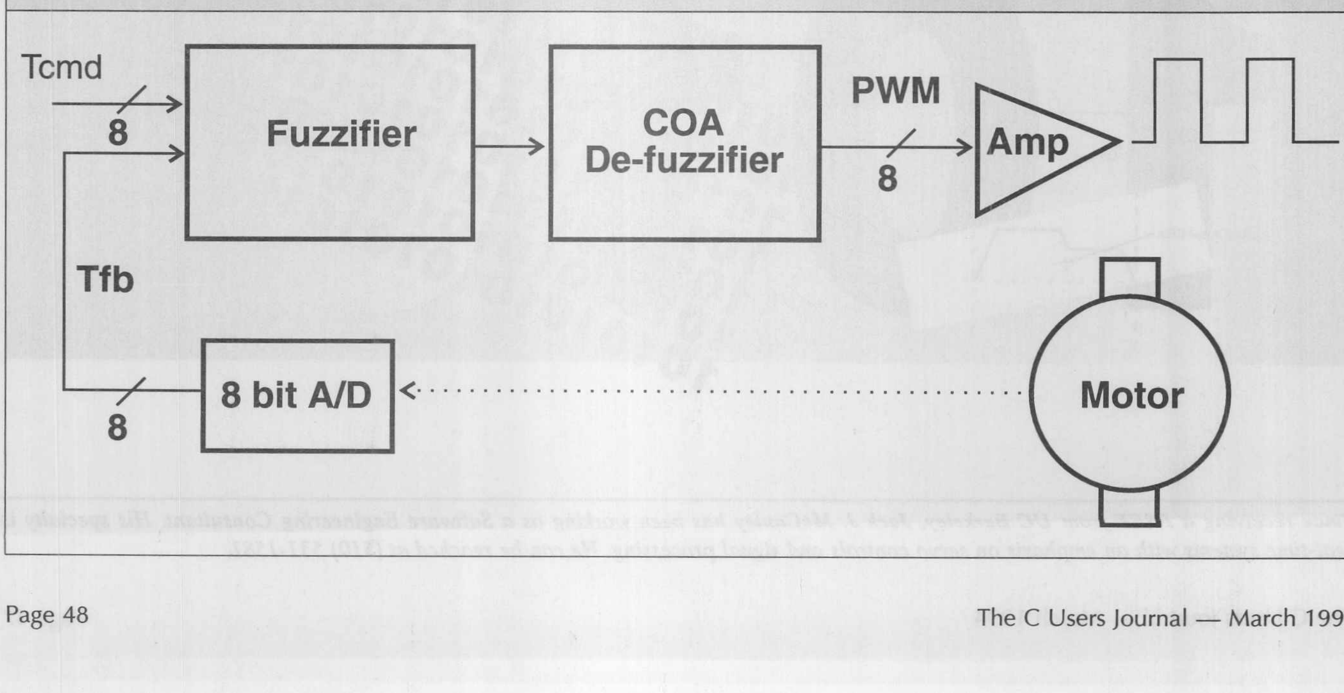


Figure 3 *Fuzzy plant for torque servo*



problems. The control problem is described as a rule base, with a rule input matrix $\mu(T)$ and a corresponding output function for that rule. When few rules are to be evaluated, simple linguistic rules can be substituted instead.

One might imagine a fuzzy set $\mu(T)$ that describes the outside temperature as "very cold," "cold," "warm," and "hot." The four members of $\mu(T)$ are linguistic operators that represent the human inferred description of the space representation of each member of $\mu(T)$. The membership function is typically a trapezoid that represents a degree of membership. The degree of membership is a real number between 0.0 and 1.0 with a degree of 1.0 meaning full membership and a degree of 0.0 indicating no membership. (See Figure 1.)

Suppose the outside temperature is –50 F. Then according to $\mu(T)$ the outside temperature will lie in the domain of "very cold." If the temperature is 12 F, the temperature might not be so much "very cold" as it is just "cold." Membership functions almost always overlap in the domain of $\mu(T)$. Fuzzy logic provides a means of dealing with overlapping domains and also domains of overlapping output sets. The math allows us to weigh the cumulative effect of all rules to generate a *crisp* output. A crisp output is also called a *de-fuzzified* output.

The typical fuzzy plant (controller) consists of one or more input fuzzy sets, a rule base, and an output fuzzy set. The input sets fuzzify using the rule base, and the output set de-fuzzifies from the inputs, rules, and the output de-fuzzifier function.

An Application

This two-input controller is a torque regulator on a DC motor. The controller topology could easily be extended to any two-input, single-output fuzzy controller.

We desire to regulate the torque applied to the shaft of a permanent-magnet DC brush motor. The torque T_{motor} applied to the shaft is a linear function of armature current I_{motor} and (to a lesser extent which will be ignored here) motor temperature. Armature current is controlled by a Pulse Width Modulated (PWM) amplifier which varies the duty cycle *DA* from 0 to 100 per cent as a linear function of input voltage.

If a positive voltage is applied to the motor terminals, a positive torque will be applied to the motor shaft. If a negative voltage is applied, a negative torque will be applied to the motor shaft. The job of the servo is to regulate the torque on the motor shaft under varying load conditions. The servo applies an adjustment to DA based on the commanded torque input, $T_{cmd}(z)$, and the feedback torque input:

$$T_{arm} = I_{motor}(z) * K_{motor}(z)$$

sensed on the motor shaft. (See Figure 2.)

The eight-bit PWM applies a positive voltage to the terminals if the PWM value is between 128 and 255. A negative voltage is applied if the value is between 0 and 126. An eight-bit A/D converter and pre-amp sense the feedback torque. The granularity of the feedback torque is determined by the radix of an eight-bit A/D converter. An eight-bit D/A (PWM) assures coherency between conversion radixes on the input. (See Figure 3.)

Fuzzy Controller for Torque

The fuzzy controller is implemented in C on an inexpensive high-integration micro-controller. A simulation program executes on a PC-AT, to assist debugging of the fuzzy servo prior to porting it to the micro-controller.

In this system the fuzzy plant is a two-input, single-output controller. Three fuzzy sets exist with the input sets occupying two dimensions of the rule base and the output set occupying the action to be performed on each rule, which is the combination pointed to by the input fuzzy set membership functions.

The first input fuzzy variable T_{error} is the error between the setpoint or command torque at time t, and the feedback torque or:

$$T_{error}(z) = T_{cmd}(z) - T_{arm}(z)$$

The second input dT_{error}/dt is the "rate of change of error" or how quickly the feedback torque at time t is changing with respect to the previous sample at time t–1:

$$dT_{err}(z)/dt = T_{arm}(z) - T_{arm}(z-1)$$

The output function $\mu(DA)$ determines the action to be performed upon evaluation of the rules. For example, if the instantaneous feedback torque is at the setpoint:

$$T_{cmd}(z) \sim T_{arm}(z)$$

but the feedback torque derivative is non-zero:

$$T_{arm}(z) > T_{arm}(z-1)$$

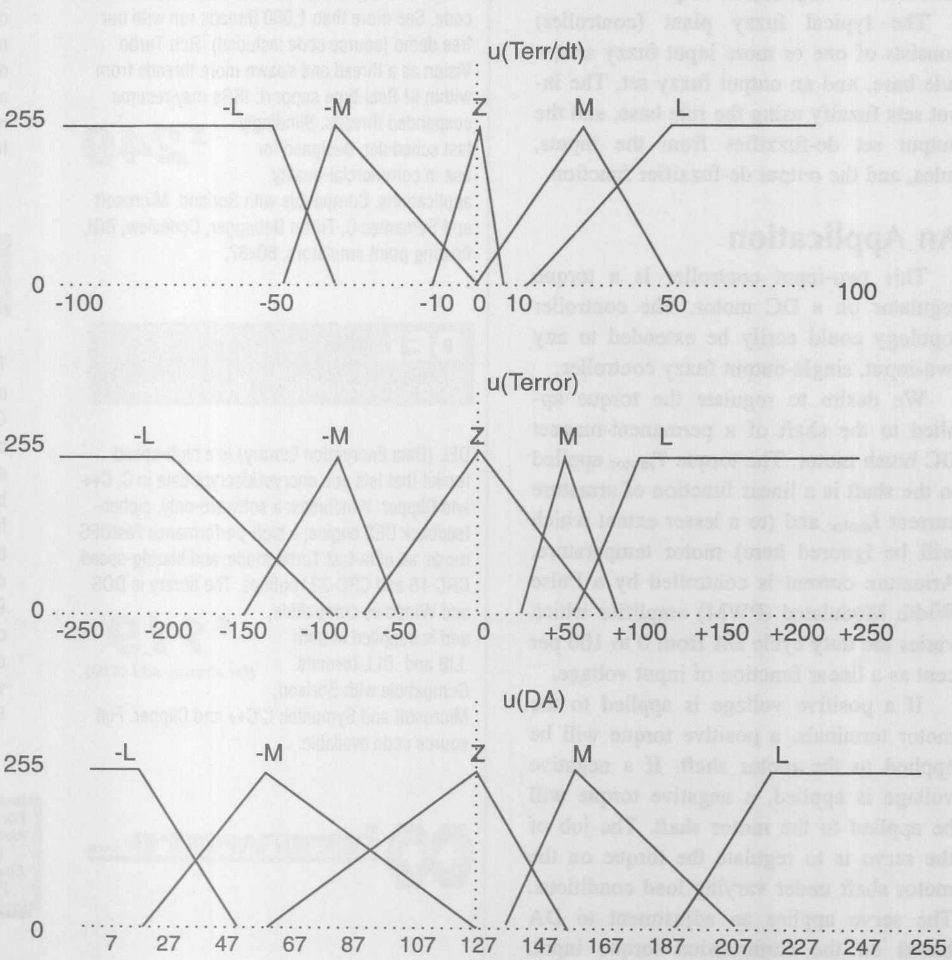
we might wish to apply a slight adjustment to DA so that $T_{error}(z)$ and $dT_{err}(z)/dt$ remain zero. The amount of adjustment applied to DA is determined by the inputs and also the output control fuzzy set $\mu(DA)$. Which membership function of $\mu(DA)$ to apply is determined by the input membership function space and the operator-inferred description of the control problem in the rule-base table. The idea is to maintain zero error and zero error derivative:

$$dT_{err}(z)/dt = T_{error}(z) = 0$$

Figure 4 *Fuzzifier rules and membership functions for 8-bit system*

dTerr/dt \ Terror	-L	-M	Z	M	L
L	Z	-M	-M	-M	-L
M	M	Z	-M	-M	-L
Z	L	M	Z	-M	-L
-M	L	M	M	Z	-M
-L	L	M	M	M	Z

Fuzzifier rule Table



✧ Request 324 on Reader Service Card ✧

The number of inputs and the dimension of each determines the rule base matrix. For example, we have two input fuzzy sets, $\mu(T(Verr)$ and $\mu(dT_{err}/dt)$, with five membership functions each. This yields a 5x5 or 25 rule-base controller. The corresponding action to be performed by the evaluation of each input rule determines the output controlling membership function $\mu(DA)$. For example, rule (3, 3) is:

IF $T_{error} == M$
    AND $dT_{err}/dt == -M$
        THEN $DA == Z$

and rule (3, 2) is:

IF $T_{error} == M$
    AND $dT_{err}/dt == Z$
        THEN $DA == M$

A literal evaluation of rule (3,2) would read, "If the feedback torque is less than the setpoint, and the feedback torque is approaching the setpoint at medium rate, then apply zero bias to the PWM." The key to fuzzy logic control is that the degrees of membership incorporate the amount of bias to apply and the degree of truth to each rule. (See Figure 4.)

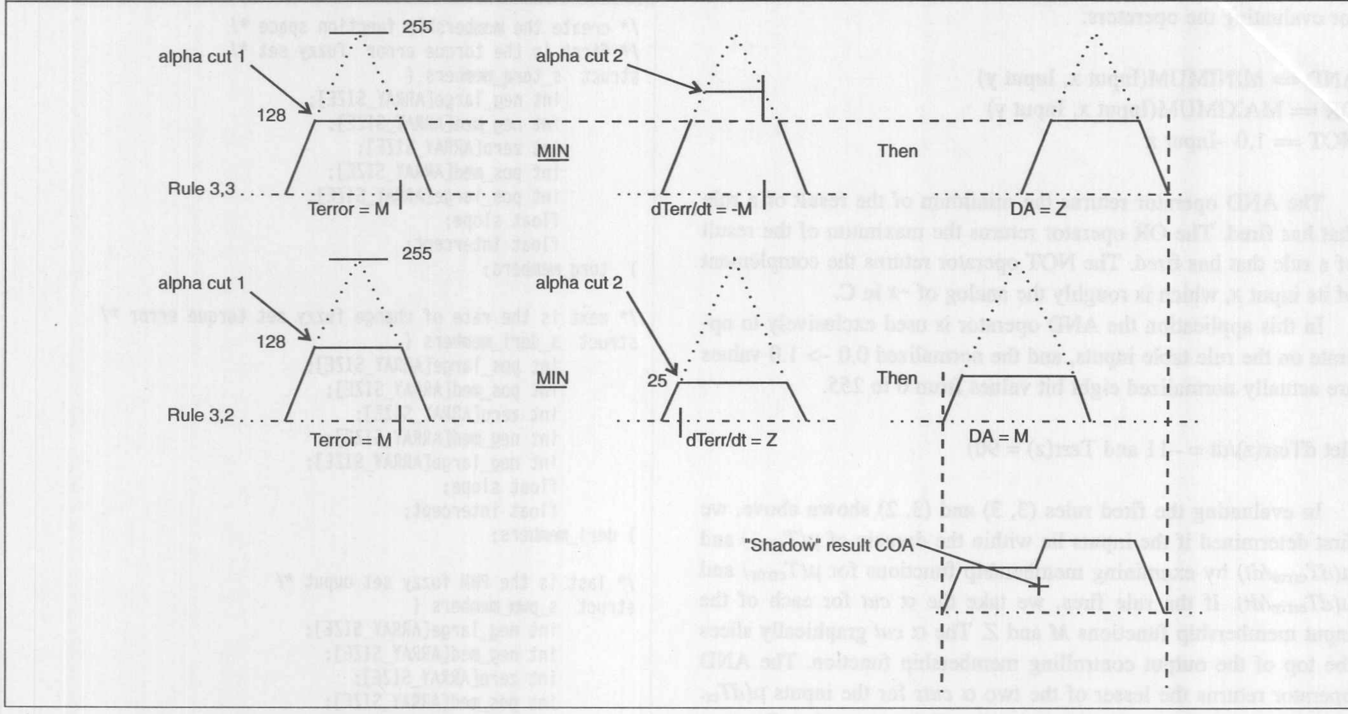
When a Rule Fires

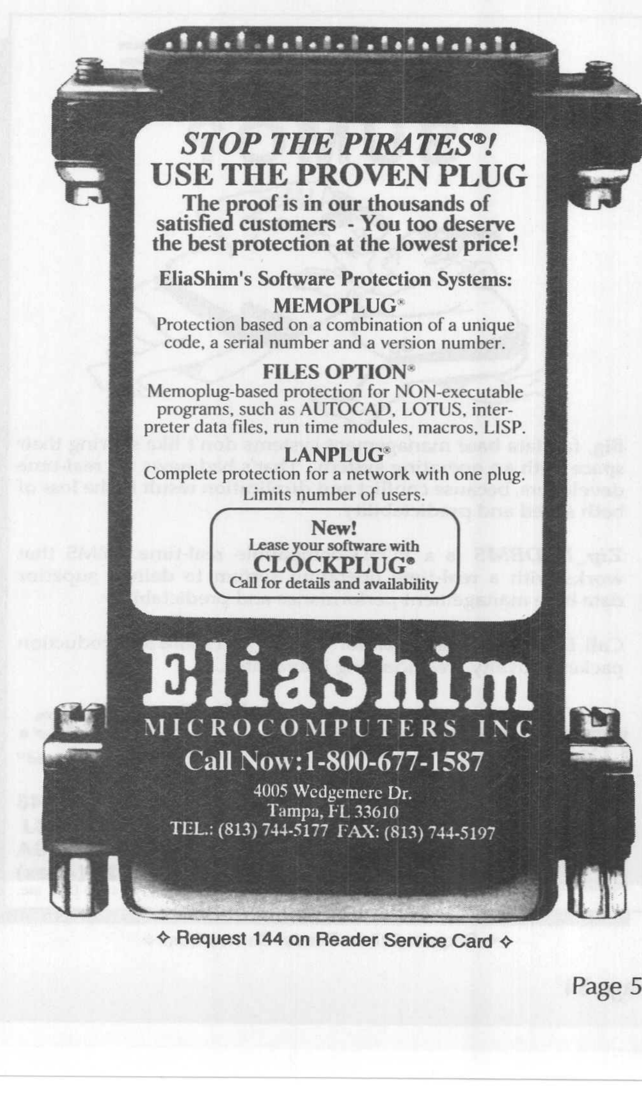
A rule *fires* when a nonzero result is returned upon evaluation of the rule. The degree to which the rule is true is incorporated in the membership functions. If the input values lie within the membership function trapezoid space, then the input is valid. A rule fires when both inputs to the rule are non-zero. A rule is evaluated using ternary operators similar in concept to Boolean operators. The operators logically follow the AND, OR, and NOT constructs.

Listing 1 *C declaration code for rule table and membership functions*

```
/*************************************************************
        File: fuzzy.h
        Date: 4/3/93
        Author: Jack J. McCauley
        Header file for fuzzy.c
*************************************************************/

/* membership function size */
#define TORQUE_MEMBERS  5
#define DER_MEMBERS 5

/* loop frequency */
#define LOOP_HZ 1

/* integrator constant z-1*/
#define SKIP 1

/* normalized value */
#define NORMAL 255

/* Current ma */
#define MAX_TORQUE 1000
#define MIN_TORQUE -1000

/* derivative */
#define MAX_DERI LOOP_HZ*MAX_TORQUE
#define MIN_DERI LOOP_HZ*MIN_TORQUE

/* pwm 1/10 % */
#define MAX_PWM     255
#define MIN_PWM     0

/* Max and Min */
#define MIN_ERROR     0
#define MAX_ERROR    255

/* size of all arrays */
#define ARRAY_SIZE  256

/* represent a normalized 0 -> 1000 = 0.0 -> 1.0 */
#define FUZZY_RADIX  NORMAL

/* fuzzy max (ternary) operator */
#define FUZ_MAX( x, y )     ((x>y) ? x : y)

/* fuzzy min (ternary) operator */
#define FUZ_MIN( x, y )     ((x<y) ? x : y)

/* fuzzy AND operator */
#define FUZ_AND( x, y )     FUZ_MIN( x, y )

/* fuzzy OR operator */
#define FUZ_OR( x, y )      FUZ_MAX( x, y )

/* fuzzy compliment operator */
#define FUZ_NOT( x )        ( FUZZY_RADIX - x )
```

Figure 5 *Example of Fuzzify ≥ Defuzzify when two rules fire*





Rules and rule bases can be built using the operators exactly like those in standard Boolean logic, but because membership functions deal with degrees of truth we must have a mechanism for evaluating the operators:

AND == MINIMUM(Input x, Input y)
OR == MAXIMUM(Input x, Input y)
NOT == 1.0 –Input x

The AND operator returns the minimum of the result of a rule that has fired. The OR operator returns the maximum of the result of a rule that has fired. The NOT operator returns the complement of its input *x*, which is roughly the analog of ~*x* in C.

In this application the AND operator is used exclusively to operate on the rule table inputs, and the normalized 0.0 –> 1.0 values are actually normalized eight bit values from 0 to 255.

(let dTerr(z)/dt = –11 and Terr(z) = 90)

In evaluating the fired rules (3, 3) and (3, 2) shown above, we first determined if the inputs lie within the domain of $\mu(T_{error})$ and $\mu(dT_{error}/dt)$ by examining membership functions for $\mu(T_{error})$ and $\mu(dT_{error}/dt)$. If the rule fires, we take the α *cut* for each of the input membership functions *M* and *Z*. The α *cut* graphically slices the top of the output controlling membership function. The AND operator returns the lesser of the two α *cuts* for the inputs $\mu(dT_{error}/dt, L)$ and $\mu(T_{error}, M)$ for use in the slicing operation. Because

Listing 1 *continued*

```
/* create the membership function space */
/* first is the torque error  fuzzy set */
struct  s_torq_members {
        int neg_large[ARRAY_SIZE];
        int neg_med[ARRAY_SIZE];
        int zero[ARRAY_SIZE];
        int pos_med[ARRAY_SIZE];
        int pos_large[ARRAY_SIZE];
        float slope;
        float intercept;
}  torq_members;

/* next is the rate of change fuzzy set torque error */
struct  s_deri_members {
        int pos_large[ARRAY_SIZE];
        int pos_med[ARRAY_SIZE];
        int zero[ARRAY_SIZE];
        int neg_med[ARRAY_SIZE];
        int neg_large[ARRAY_SIZE];
        float slope;
        float intercept;
} deri_members;

/* last is the PWM fuzzy set ouput */
struct  s_pwm_members {
        int neg_large[ARRAY_SIZE];
        int neg_med[ARRAY_SIZE];
        int zero[ARRAY_SIZE];
        int pos_med[ARRAY_SIZE];
        int pos_large[ARRAY_SIZE];
        float slope;
        float intercept;
} pwm_members;

/* define output rule table members */
#define L           pwm_members.pos_large
#define M           pwm_members.pos_med
#define Z           pwm_members.zero
#define NM          pwm_members.neg_med
#define NL          pwm_members.neg_large

/* finally the fuzzy sets */
/* torque feedback error */
int *dTerr_dt[] = {
                deri_members.pos_large  ,
                deri_members.pos_med    ,
                deri_members.zero       ,
                deri_members.neg_med    ,
                deri_members.neg_large
                };
/* torque (OZ-in) */
int *Terror[] = {
                torq_members.neg_large  ,
                torq_members.neg_med    ,
                torq_members.zero       ,
                torq_members.pos_med    ,
                torq_members.pos_large
                };

/* create the rule table and allocate space */
struct  s_rule {
        int *table[TORQUE_MEMBERS];
} rule[DER_MEMBERS] =
        /* */
        {{Z,   NM, NM, NM,  NL },
        { M,   Z,  NM, NM,  NL },
        { L,   M,  Z,  NM,  NL },
        { L,   M,  M,  Z,   NM },
        { L,   M,  M,  M,   Z  }};
```

Listing 1 *continued*

```
The Fuzzy membership functions are stored in a  look up table for all input
and output fuzzy sets. Fuzzy variables with three digits of precision are
normalized between 0 and 255 integer corresponding to an 8-bit radix converter
and a fuzzy set 0.0 - 1.0 normalized value. Look up tables increase bandwidth
and allow the servo to run with few floating point calculations.

/*********************************************************************
        File: fuzzy.c
        Date: 4/3/93
        Author: Jack J. McCauley
        fuzzy torque controller for motor
*********************************************************************/

#include "stdio.h"
#include "stdlib.h"
#include "conio.h"
#include "proto.h"
#include "fuzz.h"           /* the above file */

/*********************************************************************
        Routine: calc_slope
        Date: 4/3/93
        Author: Jack J. McCauley
        calcs line slope of two points in a plane
*********************************************************************/
float calc_slope( float x1, float x2, float y1, float y2 ) {

        float slope;
```

of the overlapping domain of the membership functions, more than one rule will typically fire. When this occurs, fuzzy logic provides a mathematical method for dealing with multiple rule firings. The output of each rule is an output membership function that has been α *cut* and is then graphically ORed with the accumulated preceding output membership functions. The resultant resembles a "shadow" of each fired rule with the accumulated output overlapping each preceding fired rule. Mathematically, the accumulation is the fuzzy OR operator (MAXIMUM) applied to the current rule that fires and the accumulated fired rules. (See Figure 5.)

De-fuzzification

The accumulated result of all firing rules occupies a two-dimensional space which is a fuzzy set with one membership function. The resultant must be converted to a real world crisp result which takes into account all applied rules. To do this, a spatial average is taken which computes the center of area (COA) of the function. COA is among several methods for computing the average. It is the method used in this application because it executes quickly.

$$COA = (25*18 + 25*31 + 128*100 + 128*127 + 128*140) / (25 + 25 + 128 + 128 + 128) = 74$$

So the *DA* value written to the PWM D/A is 74.

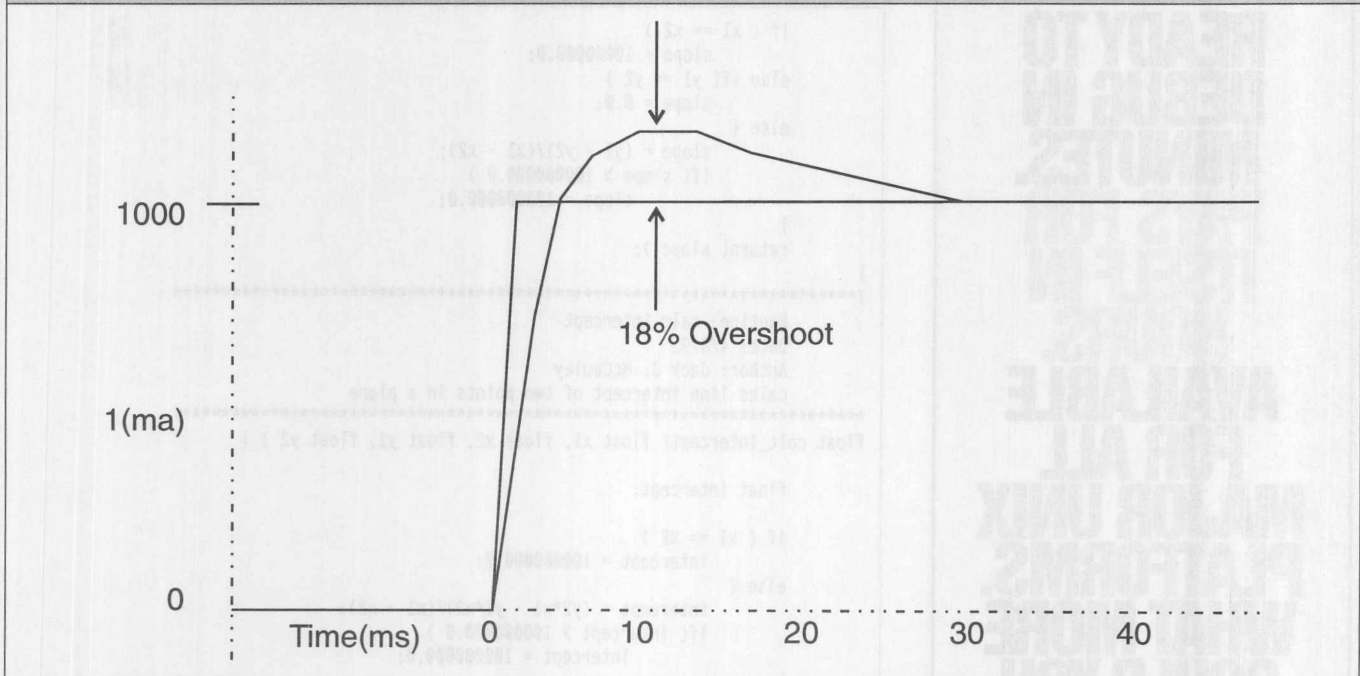
C Language Implementation

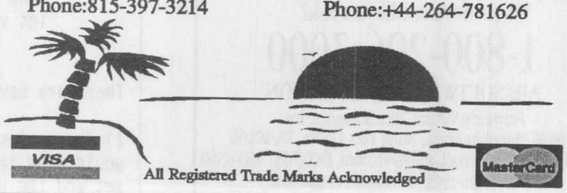
The membership functions use table look up to follow the example:

$\mu(dT_{error}/dt)$ (in oz-in):
$-L$ WHEN $dT_{err}(z)/dt <= -35$
$-M$ WHEN $-50 <= dT_{err}(z)/dt =< 0$
ZM WHEN $-10 >= dT_{err}(z)/dt <= 7$
M WHEN $0 <= dT_{err}(z)/dt <= 50$
L WHEN $dT_{err}(z)/dt >= 10$

All 25 rules are evaluated and the rules that fire result in a output according to the COA output de-fuzzifier function. The output array stores the result of the rule firing and the history of predicate rules. Conflicts are resolved using the fuzzy OR (MAXIMUM) operator. The resultant outputs contribute to a weighted sum to yield the COA output. This strategy allows for the quick computation of a crisp value using eight-bit multiplies.

Figure 6 *An illustration of de-fuzzification*





Listing 1 *continued*

```
        if ( x1 == x2 )
                slope = 10000000.0;
        else if( y1 == y2 )
                slope = 0.0;
        else {
                slope = (y1 - y2)/(x1 - x2);
                if( slope > 100000000.0 )
                        slope = 100000000.0;
        }
        return( slope );
}
/*********************************************************************
        Routine: calc_intercept
        Date: 4/3/93
        Author: Jack J. McCauley
        calcs line intercept of two points in a plane
*********************************************************************/
float calc_intercept( float x1, float x2, float y1, float y2 ) {

        float intercept;

        if ( x1 == x2 )
                intercept = 100000000.0;
        else {
                intercept = (y2*x1 - y1*x2)/(x1 - x2);
                if( intercept > 100000000.0 )
                        intercept = 100000000.0;
        }
        return( intercept );
}
/* end print_array */

/*********************************************************************
    Routine: down_load()
    Date: 4/3/93
        Author: Jack J. McCauley
initialize fuzzy membership function tables from serial port DRIVER not shown
*********************************************************************/
void down_load( int  *membership_function, int len )
{
        int k;
        char buff[32];

        /*short, tight loop */
        for( k=0; k< len; k++ ) {
                /* get ascci string from driver */
                gets( buff, 12 );
                *membership_function++ = atoi( buff );
        }
}
/* end down_load() */
/*********************************************************************
    Routine: fuzzy_init
    Date: 4/3/93
    Author: Jack J. McCauley
        initialize fuzzy membership function tables
*********************************************************************/
void fuzzy_init( void )
{
    int k;
    long slope;
        long intercept;
        int val;

/*
There are several ways to generate these tables:

1) The easiest is to simply use ROM space and store them permanently in memory. FUZZ.H
would need to be modified to  reflect the static ROM delecerations for each fuzzy
set and the values would be initialize directly attaching them to the data arrays.
```

For a micro-controller application, It was determined by experimentation that a loop repetition rate of at least 1 KHz would be required for satisfactory performance. Command set-points were entered through a serial port and an oscilloscope measured the response of the loop. Figure 6 shows the measured step response, which is quite adequate.

Conclusion

Fuzzy logic control seems to hold promise as an alternative to standard PID control. Rigid modeling is not required because the servo tuning is done via the fuzzy set membership functions and the rules. The rules incorporate Boolean statements and operator-inferred control rather than strict theoretical modeling. The membership functions allow tuning of the control system by altering the space that they occupy, and the placements of the output membership functions provide the control action to be performed by the rule. The rules use Boolean-like operators that infer a control action depending upon the degree of truth of the rule firing. A rule fires if the fuzzified inputs return a non-zero degree of truth, referred to as the *a cut* for each input.

Fuzzy logic is not as brittle as standard PID control because of the natural language approach to the control problem. Second-order effects such as temperature can be incorporated directly in the rule by logically appending another fuzzy set for temperature onto the rule. Suppose that we know that an increase in temperature causes the torque to change much more rapidly. By creating a rule base that incorporates temperature, we compensate for the change, as in:

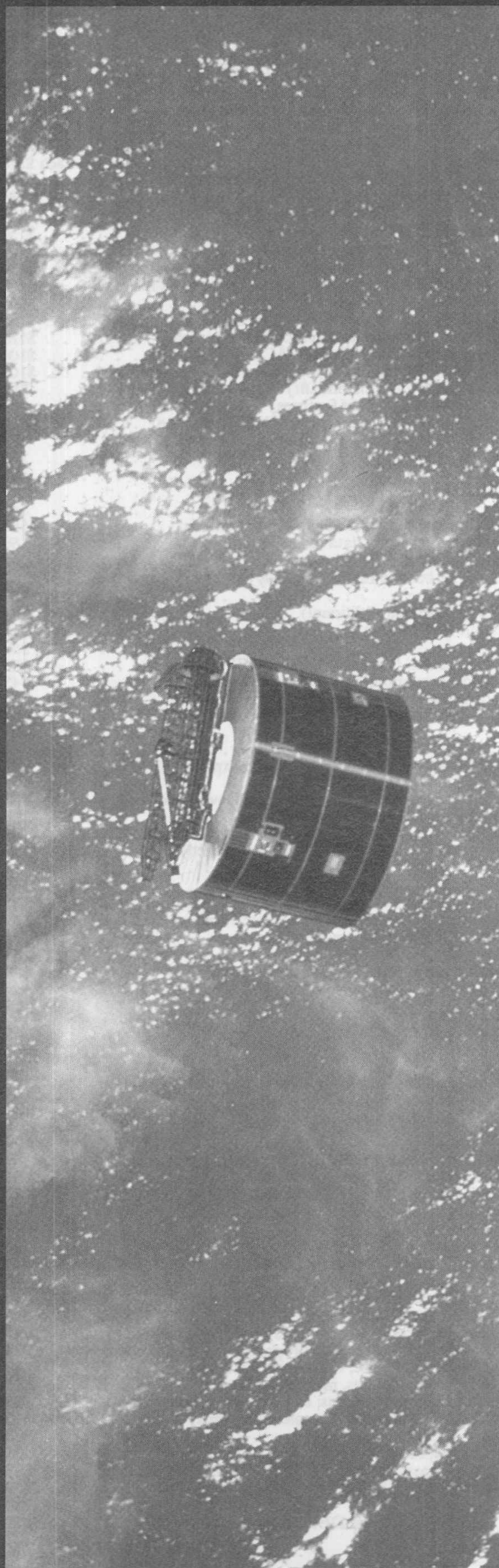
IF $T_{\mathrm{error}} == M$
  AND $dT_{\mathrm{err}}/dt == -\mathrm{M}$
  AND $Temperature == L$
    THEN $DA = M$

In PID control second-order variables such as temperatures are not so easily incorporated into the model.

The fuzzy controller is also less prone to radix overflow and underflow problems. In this application, the controller was implemented using eight-bit LUTs. All mathematical operations were cast to 32-bit `long`, thus preventing overflow. Because of the averaging nature of COA, it is inherently safe from overflow. □

Listing 1 *continued*

```
2) Down load the fuzzy sets through the serial port as I did in the
tuning of this servo. In which case I've included that code here  (of
course in the ROM version of the system  you'll need 1)).

3) Store the slope-intercept form of each membership function and
calculate the line slopes and intercepts
*/

/*
Membership functions are downloaded through the serial port from a file in ASCII
format one set member at a time. In this  system I used a spreadsheet and
graphical interface to actually draw the membership functions with a mouse.
This aided in  tuning the servo substantailly. In the ROH version of the system,
I wrote a small programm to append the ROM statics  memberships to fuzz.h.
*/
        down_load( deri_members.neg_large, ARRAY_SIZE);
        down_load( torq_members.neg_large, ARRAY_SIZE);
        down_load( pwm_members.neg_large, ARRAY_SIZE);
        down_load( deri_members.neg_med, ARRAY_SIZE);
        down_load( torq_members.neg_med, ARRAY_SIZE);
        down_load( deri_members.zero, ARRAY_SIZE);
        down_load( torq_members.zero, ARRAY_SIZE);
        down_load( pwm_members.zero, ARRAY_SIZE);
        down_load( deri_members.pos_med, ARRAY_SIZE);
        down_load( orq_members.pos_med, ARRAY_SIZE);
        down_load( pwm_members.pos_med, ARRAY_SIZE);
        down_load( deri_members.pos_large, ARRAY_SIZE);
        down_load( torq_members.pos_large, ARRAY_SIZE);
        down_load( pwm_members.pos_large, ARRAY_SIZE);

        /* slope intercept line calculation */

        /* these line equations are used for scaling the
           crisp values from the above arrays */
        deri_members.slope = calc_slope(MIN_DERI, MAX_DERI, 0, ARRAY_SIZE-1 );
        deri_members.intercept = calc_intercept(MIN_DERI, MAX_DERI, 0, ARRAY_SIZE-1  );

        torq_members.slope = calc_slope( MIN_TORQUE, MAX_TORQUE, 0, ARRAY_SIZE-1 );
        torq_members.intercept = calc_intercept(MIN_TORQUE, MAX_TORQUE, 0, ARRAY_SIZE-1 );

        pwm_members.slope = calc_slope(0, ARRAY_SIZE-1, MIN_PWM, MAX_PWM);
        pwm_members.intercept = calc_intercept(0, ARRAY_SIZE-1, MIN_PWM, MAX_PWM);
/*
        for( k=0; k<ARRAY_SIZE; k++ )
                printf("%d %4d %4d %4d %4d
%4d\n",k,deri_members.pos_large[k],deri_members.pos_med[k],
deri_members.zero[k],deri_members.neg_med[k],deri_memb
ers.neg_large[k]);
*/
}
/* end FUZZINIT */

/*********************************************************************
        Routine: defuzzify_COA
        Date: 4/3/93
        Author: Jack J. McCauley
        defuzzify using COA
*********************************************************************/
float defuzzify_COA( int *output ) {

        static long k;
        static long numerator, denominator, val;

        numerator = 0;
        denominator = 0;

        for ( k=0; k<ARRAY_SIZE; k+=SKIP ) {

                val = (long)*output;
```

Listing 1 *continued*

```
            output+=SKIP;
            /* look for non-zero values and include in our COA calc */
            if( val ) {
                    denominator += val;
                    /* ROM based later */
                    numerator += val *(long)k;
            }

    }

    /* divide if non-zero x/D */
    if( denominator ) {
            /* return crisp value */
            /* Could be converted from float if desired */
            numerator = (long)((float)(numerator/denominator) * pwm_members.slope +
    pwm_members.intercept);
            return( numerator );
    } else
            return( 0 );

}
/* end COA calc */

/*********************************************************************
        Routine: fuzzify
        Date: 4/3/93
        Author: Jack J. McCauley
        fuzzifier for our servo
*********************************************************************/
int fuzzify(    int derr_dt, int err,
                int *p_Terror, int *p_dTerror,
                int *p_out, int *resultant ) {

        static int k, val, alpha_cut, temp, *moe;

                /*      COA method      */
        /*
Get the alpha cut for error and derivative.  Use the AND (min) operator and cut the
output , a non-zero fuzzy MIN indicates a rule has fired , write the cut to the result
array by "shadowing" the exisiting using the MAX operator
        */

        /* normalize the output derivative */
        moe = resultant;

        /* Find out if the rule fired. If the rule fired then get the alpha cut */
        if( (alpha_cut = FUZ_AND( p_dTerror[derr_dt], p_Terror[err] )) != 0 ) {
                for ( k=0; k<ARRAY_SIZE; k+=SKIP ) {
                /*
                An interesting effect will be noticed if the skip is set greater than
                 1. In this system setting skip to lets say 2 or three will yield
                in most circumstance yield the same defuzzified crisp output if the
                 slope of the membership functions are not too steep.
                The other benifit is that the execution speed is increased greatly
                */
                        /* create shadow */
                        val = *p_out;
                        /* don't get bit by shortcuts *./
                        val = FUZ_MIN( alpha_cut, val );
                        temp = *resultant;
                        *resultant = FUZ_MAX( temp, val );
                        resultant+=SKIP;
                        p_out+=SKIP;
                }
                /* rule fired */
                return( 1 );
        } else
                /* rule didn't fire */
                return( 0 );
```

Listing 1 *continued*

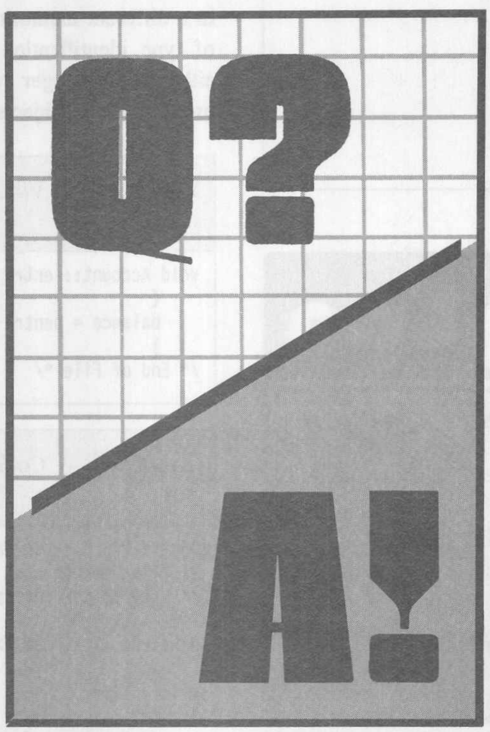
```
}
/* end FUZZIFICATION calc */

/*******************************************************************
        Routine: servo_torque
        Date: 4/3/93
        Author: Jack J. McCauley
        fuzzy servos to torque set point
*****************'**************************************************/
/*
Routine would run as an ISR attched to a timer interrupt passed values are read
from and A/D convertor and command torque (serial port etc..)
*/
long servo_torque( int error, int derr_dt )
{
        /* statics for speed */
        static int row, column;

        /* pointers to tables */
        static int *p_out, *p_dTerr_dt, *p_Terror;

        /* COA container class */
        static int resultant[ARRAY_SIZE];

        /* zero fill the array */
        for( row = 0; row<ARRAY_SIZE; row++ )
                resultant[row] = 0;

        /* normalizing the error derivative will allow the error to ff
        /* normalize error derivative to look up table RADIX*/
        error = (long)((float)error * torq_members.slope + torq_members.intercept);

        /* normalize error derivative*/
        derr_dt = (long)((float)derr_dt*deri_members.slope + deri_members.intercept);

        /* MAX and MIN error */
        if( error > MAX_ERROR )
                error = MAX_ERROR;
        else if( error < MIN_ERROR )
                error = MIN_ERROR;

        /* MAX and MIN derivative */
        if( derr_dt > MAX_DERI )
                derr_dt = MAX_DERI;
        else if( derr_dt < MIN_DERI )
                derr_dt = MIN_DERI;

        /* traverse the rule table and evaluate the rules */
        for( row = 0; row < DER_MEMBERS; row++ ) {

                /* get pointers to tables from data structures */
                p_dTerr_dt = dTerr_dt[row];
                for( column = 0; column < TORQUE_MEMBERS; column++ ) {

                        /* get pointers to tables from data structures */
                        /* get the output membership function for that rule evaluation */
                        p_out = rule[row].table[column];
                        p_Terror = Terror[column];
                        /* fuzzify the rule */
                        fuzzify( derr_dt, error, p_Terror, p_dTerr_dt, p_out, resultant );
                }
        }

        /* defuzzify using COA */
        return( defuzzify_COA( resultant ) );

        /* return the fired rules */
}

/* END */
```

Run-Time Type Checking in C++

Run-Time Typing

I have taught myself C++ and am comfortable with most of its concepts. There is one aspect that I am unsure about. Bjarne Stroustrup, in his book *The C++ Programming Language* states: "using run-time type inquiries ... destroys all modularity in a program and negates the aims of object-oriented programming." I attempt to adhere to this suggestion, but there is a situation in which I don't know how to apply the rule: reading and writing objects to data files. As an example, let's suppose we are writing a simple checkbook balancing program. The base object is an *Entry*, which corresponds to something you would enter in your checkbook. Derived from base class *Entry* are three classes which can be instantiated: *Check* (a written bank draft), *Deposit* (a bank window deposit), and *Withdrawal* (a window withdrawal). Keeping track of the type of objects in memory is easy, since when one of the three derived classes is created, it is done through a constructor which builds in type information. There are many ways to write the checkbook entries to a data file, so let's assume we just write a character-based representation to the file. The question is how can we write the data so that we can read the information back into memory? The only way I can think of is to include type information, such as an integer coded for each class type. This method violates Mr. Stroustrup's rule, though. Any thoughts you have on this matter would be greatly appreciated.

Paul Waldo
Forest, VA



A One reason Bjorne was against run-time checking was because it enables programmers to avoid derivation. For example, suppose you have a *type_of* function that can identify the *Entry* type of a pointer. To post an entry, you might code something that looks like Listing 1. If you need to add an additional type of *Entry*, then you have to add another case to the switch statement.

However, there's a cleaner way to handle this problem. Suppose you give *Entry* a pure virtual *post* function. Each class derived from *Entry* now supplies its own *post* function. The *post_entry* function could look like Listing 2. When adding a new derived class, you do not need to change the *post_entry* function. You just provide a *post* function for the new class.

As you have suggested, virtual functions only work while objects are in memory. Each object of a class with virtual functions contains a pointer to a table of function pointers (the vtable, as it is sometimes referred to). All objects of a particular class contain a pointer to the same table. When the program calls a virtual member function it uses the pointer to the corresponding function in the vtable. In a sense, this vtable pointer uniquely identifies the class type of an object. In fact, some compilers have non-standard extensions that can use this pointer to provide a form of run-time type identification. Other vendors provide alternative methods for run-time identification. Microsoft has a *CRuntimeClass* object associated with each class that is used with the *IsKindOf* function. With this function, you can determine if an object belongs to a particular class or if it is derived from a class. (The class must be derived from the Microsoft *CObject* class to work with *IsKindOf*.) To use the *IsKindOf* function, you include a *DECLARE_DYNAMIC* macro in the class definition and an *IMPLEMENT_DYNAMIC* macro in the class implementation. *CRuntimeClass* is the data type used to store class information. You can obtain a pointer to an object of this type with:

```
CRuntimeClass * pclass = RUNTIME_CLASS(Your_class);
```

Kenneth Pugh, a principal in Pugh-Killeen Associates, teaches C and C++ language courses for corporations. He is the author of All On C, C for COBOL Programmers, *and* UNIX for MS-DOS Users, *and was a member of the ANSI C committee. He also does custom C/C++ programming and provides SystemArchitectonics™ services. His address is 4201 University Dr., Suite 102, Durham, NC 27707. You may fax questions for Ken to (919) 489-5239. Ken also receives email at* kpugh@allen.com *(Internet) and on Compuserve 70125,1142.*

Typically you do not use the information in *CRuntimeClass* directly, but instead pass it to *IskindOf*. For example, as shown in the following code fragment, you might want to cast a base class pointer to a pointer to a real object. To be logically correct, you need to be sure the object pointed to belongs to a particular class.

```
CObject * pyour_object = new Your_class;
...
if ( pyour_object->IsKindOf( RUNTIME_CLASS(Your_class) ) )
    {
    // Cast it
    Your_class * p_this_object =
        (Your_class *) pyour_object;
    }
```

You can use this type information to create objects of a given class. The *CRuntimeClass* class provides a member function *CreateObject* for dynamically creating objects. The use of *CreateObject* is demonstrated as follows:

```
CRuntimeClass * p_your_class = RUNTIME_CLASS(Your_class);
// Create it
CObject * pyour_object =
    p_your_class->CreateObject();
// Cast it to the class
Your_class * p_this_object =
    (Your_class *) pyour_object;
```

In your question, you have run across one area of programming that requires some form of type identification: permanent or persistent storage. You cannot use the address of a vtable as the identification means for an object. When the contents of an object are read back into memory, the chances are that the vtable will be in a different memory location. You will need to store some form of type identification with the object. This identification could either be an integer value or the string name of the class. If your program stores objects in a known sequence and retrieves them by

Listing 1 *One way to do run-time type checking*

```
void Account::entry_post(Entry * pentry)
    {
    switch(type_of(pentry))
        {
    case Deposit_entry:
        balance += pentry->amount;
        break;
    case Check_entry:
        balance -= pentry->amount;
        break;
    case Withdrawal_entry:
        balance -= pentry->amount;
        break;
        }
 /* End of File */
```

Listing 2 *Virtual functions simplify run-time type checking*

```
void Account:: entry_post(Entry * pentry)
    {
    balance = pentry->post(balance);
    }
/* End of File */
```

Listing 3 *Code that one compiler didn't like*

```
/* GRM-P45.C -- Graham, Learning C++, p. 45 */
// File rabbits.ccp
// Program for inverse Fibonacci rabbit problem

#include <iostream.h>

main()
    {
    // Get input from user

    long current;   // number of pairs this month
    long fertile;   // number of fertile pairs
    long needed;    // number of pairs needed
    ...
    }

Error messages:
Compiling C:\GRM-P45.C:
    Error E:\TC\INCLUDE\IOSTREAM.H 38: Declaration syntax error
    Error E:\TC\INCLUDE\IOSTREAM.H 39: Declaration syntax error
    Error E:\TC\INCLUDE\IOSTREAM.H 42: Declaration syntax error
    ...
// End of File
```

the same known sequence, then you do not need any type identification stored with the object. For example, if you always store *Checks* starting at the first position in the file, followed by *Deposits* and then *Withdrawals*, you can determine the type of an object by its position in the file. In your example, you cannot assume this kind of ordering exists, so you *must* store a class identifier. There are lots of ways to store this identifier, depending on how your classes are organized. Let's assume you have some unique identifier for each account entry type, such as:

```
enum Entry_type {Entry_check, Entry_deposit,
    Entry_withdrawal};
```

One of these values would be stored away with each object. For example, if your compiler provides run-time type identification with *type_of*, you might code:

```
Entry::save()
    {
    if ( this->type_of() == Check )
        // Store Entry_check
    else if (this->type_of() ==
            Deposit )
        // Store Entry_deposit
        else if (this->type_of() ==
                Withdrawal )
            // Store Entry_withdrawal)

    ...
    // Store remaining contents
    // in an account
    }
```

Before I get too much mail regarding this "hidden switch statement," let me explain that this function is complementary to the retrieval function, which I will show shortly. You could use a virtual function for *save* in each of the derived classes. The function would store the appropriate *Entry_type* value, call a *save* function in the *Entry* class to store the data members in that class, and then save its own data members. If you were using the Microsoft compiler, this type checking code might look like the following fragment. However, Microsoft provides other functions that make this code unnecessary, as we shall see shortly.

```
Entry::save()
    {
    CRuntimeClass * pcheck_class
        = RUNTIME_CLASS(Check);
    CRuntimeClass * pdeposit_class
        = RUNTIME_CLASS(Deposit);
    CRuntimeClass * pwithdrawal_class
        = RUNTIME_CLASS(Withdrawal);
    if ( this->IsKindOf(pcheck) )
        // Store Entry_check
    else if (this->IsKindOf(pdeposit) )
        // Store Entry_deposit
        else if (this->IsKindOf(pwithdrawal) )
            // Store Entry_withdrawal)
    ...
    // Store remaining contents in an account
    }
```

The basic dilemma comes in retrieving the objects. You cannot use a *retrieve* function for each derived class, as you do not know the type of entry for the next object stored in the file. Thus you can only retrieve an *entry* as a base class object. For example, the caller might use something that looks like:

```
Entry *pentry;
Account account;
...
account.retrieve_next(&pentry);
```

The *retrieve_next* function could look like the following:

```
int Account::retrieve_next(Entry **pentry_in)
    {
    // Get rid of old pointer
    Entry *pentry = *pentry_in;
    if (*pentry != NULL)
        delete pentry;
    // Read the record off disk
    // Then check the type of the record ready
    if (type == Entry_check)
        *pentry = new Check;
    else if (type == Entry_deposit)
        *pentry = new Deposit;
    else if (type == Entry_withdrawal)
        *pentry = new Withdrawal;
    // Move associated data into the type
    ...
    // Then return the pointer
    *pentry_in = pentry;
    }
```

The caller passes this function a pointer to pointer to the *Entry* class. The function deletes the *Entry* that was pointed to by *pentry_in*. The *Entry* class should provide a virtual destructor, so that any additional data members in the derived classes are deallocated. Based on the *Entry_type* value stored in the file, the function allocates the appropriate pointer. The function moves the necessary data from the file into the new object and returns the value of the pointer. If necessary, each derived class can include a function that reads any additional data members from the file.

The Microsoft archive retrieval function *(CArchive::operator>>)* does not require this if-else structure. The storage function *(CArchive::operator<<)* stores a run-time class identifier (the name of the class) in the file. When the retrieval function reads the file, it dynamically creates an object of the stored class and loads the information from the file into that object. Microsoft's multi-pronged approach to run-time typing eliminates worries about the details of persistent object storage and retrieval. All you have to do is to include the necessary macros in your object header file and your object implementation file.

C++ Problems

I am an agricultural economist at the U.S. Department of Agriculture and am trying to learn C and C++. I have bought over ten books on C, and am reading them and keying in the exercises to practice the concepts. One of the books I have bought is *Learning C++*, by Neil Graham. I began keying in one of the exercises (in C++) and the program gave me a bunch of iostream declaration errors when I attempted to compile the source code using Borland Turbo C++, 1991 (Listing 3). I saw your column in *The C Users Journal* and thought that you might be willing to suggest what is wrong, and how I might fix it. Also, do you have any recommendations for textbooks and/or diskette tutorials that may be useful in learning C and C++?

Kenneth W. Erickson
Washington, D.C.

A Reading several books and trying their examples is an excellent way to learn a new language. You can get a good feel for alternative ways of approaching problems. However, when you use only books for learning, you often run into problems for which a book has no answer. Many times I've been in the same quandary when using vendor-supplied manuals. In some cases the solution to my problem was simple but the manual just didn't deal with the problem.

In your case, what appears to be an unexplainable error is caused by a simple glitch. You named the program with a ".c" extension. The compiler took this to mean that your program was to be compiled as a C program. Inside the *iostream.h* file are several C++ syntactic constructs (such as *class*). The compiler reported error messages for these constructs since they do not exist in C. If you had named the program with a .cpp extension, the compiler would have cleanly compiled the program. You might have been confused if you compiled other C++ programs without

errors and therefore you thought there was something wrong with this program. Many compilers (such as Borland), have a switch that compiles .c files as C++ programs. If this option was set in your configuration file for previous programs, then other C++ programs with .c extensions would have compiled properly. If you switched around directories or reinstalled the compiler, the switch may have been reset.

There are numerous books out on C. Many are based on your knowledge of other languages. My book *C Language for Programmers* (QED) gives comparisons of C constructs with COBOL, PASCAL, PL/1, BASIC, and FORTRAN. My new book *C Language for COBOL Programmers* (QED) presents very detailed comparisons between COBOL language statements and C. *All on C* (Harper Collins) explains C without comparisons to other languages, but with numerous examples. In the C++ arena, I suggest *C++ Programming and Fundamental Concepts* by Anderson and Heinze (Prentice-Hall). I use that book as a supplementary book for my C++ courses.

User interface

Q I am new to the C language and am having a problem that you might help me with. I am writing a football card data base, and need help with the user interface. What I am trying to do is let the user of my program enter required information without pressing the enter key. I also want the user to be able to move from one data entry field to another using the arrow and home keys of the key pad. If the user presses the arrow keys the highlighted field would move up or down as required, but if a letter key or a number key was pressed, the letter or number would be concatenated to the appropriate char string variable. The concatenating part I can handle. It's getting the input that's giving me the problem. I've tried many different approaches to make this work, but still no luck. If you could help me with this problem I would be very grateful. I'm a subscriber to the *C Users Journal*, and will be checking the Questions & Answers section to see if you can solve my problem. I am using Borland C++ version 3.0 (DOS).

Randy Jones
Ruther Glen, VA

A As you have discovered, data-field entry functions are not included in the Standard C libraries. Numerous shareware and commercially-available libraries will perform the operations you list. For a listing of available shareware consult *The C User's Group Public Domain Catalog* [available for free upon request from R&D Publications, 1601 W. 23rd St., Lawrence, KS 66046. Ph: (913)-841-1631. Fax: (913)-841-2624. e-mail: `cujsub@rdpub.com`. Perusing *The C Users' Journal* itself will reveal a number of the major vendors of display packages. Since for the past year I have been programming almost exclusively in Microsoft Windows using Visual C++, I haven't kept up with all the different features of the commercial packages. Many of these packages have integrated screen designers/code generators. With such a system, you can layout your screens with a mouse or cursor keys, rather than by writing individual function calls for each field. In case you can't find what you want in either the catalog or the ads, my book *All on C* shows a sample implementation of a package of display functions providing most of the features you requested. □

Weight Reduction Techniques in C++

Randy Kamradt

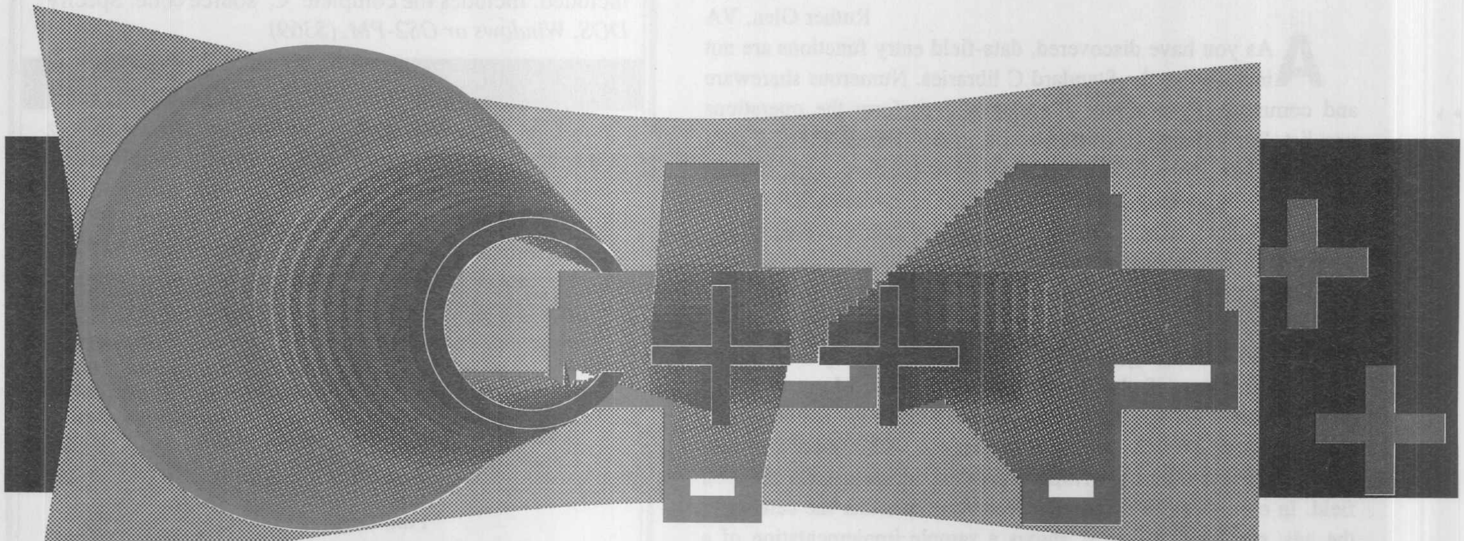
Introduction

I have been working on a large scale database downsizing project for the Ventura County School District since the beginning of 1993. Recently we turned over to the users the first application, a teaching-credential tracking database. Instead of the ticker tape parade we had expected, all they did was comment on how slow it seemed to run. Even though we used all the latest buzz words — such as "object-oriented" and "client-server" — we had to admit it was very sluggish. So we began an intense optimization effort, putting our application on a crash course of exercise and diet, to get it down to size and up to speed. This article deals with the potential problems facing object-oriented programming in C++ and some of the solutions we used.

One of the major advantages to object-oriented programming is that it can hide complexity. Very complicated sub-systems can be wrapped by classes. These classes provide well defined interactions, making their objects relatively immune to environmental factors. The down side to this is that the application programmer may not be aware of all the ramifications of using an object. Objects may encapsulate the acquisition of system resources, or they may create sub-objects. Just declaring a local variable can be a costly procedure.

One problem that faced us early on was from a class of the Commonbase Database class library, `DBTable`. Just creating a variable of type `DBTable` had the side effect of opening a communication channel (socket) to the database server. We were allocating `DBTable` objects from free store and in rare cases they never got deleted. Since our networking software had only 20 sockets available, the application would run fine for a while and then run out of sockets. This is actually an old problem, familiar to C programmers, but with a new twist: more than memory might be allocated by creating a user-defined type. Since this caused the program to die it was fixed early on, but other similar problems existed. We had to automate the creation of each `DBTable`, so as not to create it until it was needed, and to delete it as soon as possible. It could not be left up to the application programmer.

Another side of complexity hiding is that an object may be a front for many sub-objects. One of our objects, `BMOJoin` (Business Model Object Join), contained a list of `DBTable`s. A *join* is database jargon for a relational combination of tables. Since a `DBTable` holds one socket, a `BMOJoin` can hold many. To add to this problem, another object, `BMOIterator` has a pointer to a `BMOJoin`. As I will explain later, the `BMOIterator` was the key to controlling all these resources, and minimizing their allocation.



Another class, `ACond`, represents a logical condition. It is implemented as an expression tree. So doing a simple assignment of an `ACond` could be costly. Again this is actually an old problem, the only difference being that in C such copying can be done only by calling a function, while in C++ the function can be initiated with an assignment operator. C programmers know that calling a function can take time and resources, but using built-in operators always takes (relatively small) constant time and never takes system resources. These assumptions go out the window in C++.

Free-store usage is another problem. Just opening a window and tieing it to a database in our application takes thousands of memory allocations, some of them just for a few bytes. Memory allocation is the lifeblood of C++ programming because objects should be made autonomous, and cannot rely on outside sources such as local or global variables for their internal memory space.

A string class, for instance, typically contains a pointer to memory containing the string (see Figure 1). That memory must come from free store if the class is to be considered general purpose. If the memory came from outside the class, the string could not delete it when it was done, and the user would have to delete it if necessary. The issue of pointer ownership is important in making a safe application, and helps alleviate some of the common C pointer troubles such as deleting memory twice, or forgetting to delete it at all. It also means that memory allocation and copying may be done more often than absolutely necessary.

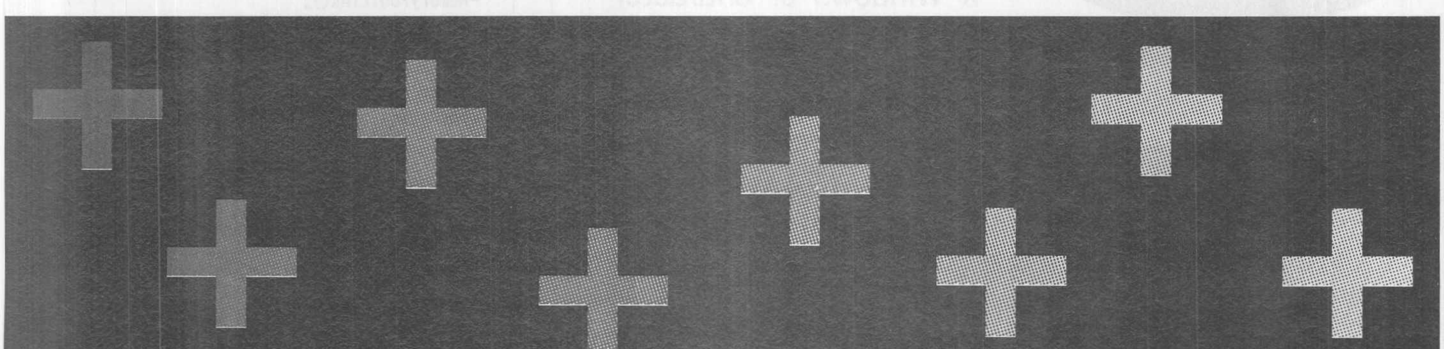
Another problem introduced with object-oriented programming is over-generalization. With base classes one can provide the common subset of functions available from a set of derived classes. If the programmer uses the base class, the full set of functions may not be available. An example of this is the use of a list object. A list object might be represented either by a linked list or by an array. If the programmer uses a list and needs to get to the *n*-th object, indexing may not be an option. The programmer will have to iterate through the list, keeping a count. If the programmer uses an array object, indexing is available.

Another example of this is the use of a complex number class. The operation `(2 + 0i) * (6 + 0i)` can be calculated much easier as `2 * 6`. Because the more general form is used, the optimization for a special case is missed. The ability to generalize is a major plus for C++, but can limit optimization.

Code Bloat

Another issue I deal with here is code bloat. I used to think a program was big if I had to leave small model (greater than 64 kilobytes of code or data). Our current application is about 1.5 megabytes and growing (from about 30,000 lines of code and two libraries). Part of this growth stems from the tendency to make objects all-purpose (or worse, multi-purpose). Poorly designed objects often give liberal access to their internals, or multiple methods of access. A well designed object should do one thing, one way, and do it well. The public interface should be minimal in order to guide the programmer to the expected usage, and to keep things simple.

Making matters worse, currently the linkers I use (Borland's tlink and HP-UX ld) always link in all virtual functions even if they are never used. This is because all virtual functions are referenced in an object's virtual table, which is included with a class constructor. I have heard that new linkers are addressing this problem, but without thorough evaluation of all the code, they will have trouble determining whether any one virtual function will assuredly be called (or assuredly *not* be called).



Randy Kamradt has been programming in C/C++ for the past seven years. He is currently working for TEAM Software, a fashionably lean consutling company developing an integrated database package for the Ventura County Superintendent of Schools, in Ventura California.

Figure 1 *Good objects must do their own memory management*

```
class BadString {
public:
// Using the pointer directly:
  BadString(char *s) { ptr = s; }
// Where did pointer come from:
  ~BadString() { delete[] ptr; }
private:
  char *ptr;
};

char *strdup(const char *str)
{
  return strcpy(new
    char[strlen(str)+1],str);
}

class GoodString {
public:
// Don't use the pointer, copy it:
  GoodString(const char *s)
    { ptr = strdup(s); }
// Now you can safely delete it:
  ~GoodString()
    { delete[] ptr; }
private:
  char *ptr;
};

// End of File
```

Another culprit in code bloat is the inline function. In the C++ style of object-oriented programming, small functions are very prevalent, and inline functions are necessary for a well oiled program. The factor that should decide whether a function is inline is the ratio of time spent calling the function to the time spent inside the function. If the time spent inside the function is much greater than the time spent calling the function, making it inline won't help speed much and will simply contribute to excessive code size. This implies that to use inlines effectively one should be aware of the inner workings of the compiler, and all of the side effects caused by some C++ functions.

Figure 2 *Using the profiler to find hidden problems*

```
// Why isn't the while loop
// ever executed?

time    count
0.0012  50   int flag = 0;
0.0031  50   while(flag = 0)
             {
0.0000  0      if(doTillTrue())
0.0000  0        flag = 1;
             }

// End of File
```

One of the best ways to optimize is to use a profiler. I used the Borland Windows profiler extensively while optimizing. In spite of its tendency to crash, or reboot my computer occasionally, it was a tremendous help not only in optimizing, but in finding bugs and memory leaks. The Borland profiler is interactive, much like a visual debugger. It allows you to stop the program at any point to examine statistics collected, to turn profiling on and off during a single run, and to selectively profile portions of the code. It provides time spent on a single line of code, and the number of times a single line is called. This can be very handy for finding hidden bugs (see Figure 2).

Profiling event-driven programs can be a challenge since the main loop of the program may be inaccessible. The method I

Listing 1 *Defines class* MemoryPool

```
#ifndef MEMPOOL_H
#define MEMPOOL_H

#include <stddef.h>

const CharSize = 8;
const PoolSize =
  sizeof(unsigned long)*CharSize;

class MemoryPoolLink {
private:
friend class MemoryPool;
  MemoryPoolLink(size_t _size,
    MemoryPoolLink *_next);
  ~MemoryPoolLink();
  void *malloc(size_t size);
  void free(void *, size_t size);
  unsigned long bits;
  MemoryPoolLink *next;
  char *data;
};

class MemoryPool {
  MemoryPoolLink freeHead;
  MemoryPoolLink usedHead;
  size_t size;
public:
  MemoryPool(size_t size);
  void *add();
  void *malloc();
  void free(void *);
};

#endif
```

used was to profile each of the main classes of the program individually. Since we keep all of the code for a class in one module, that meant compiling that module with the debugging option on. In the profiler I could then set a profile area on every line in the module. After running the program and doing a few transactions that would exercise the class I was profiling, the statistics window would show me where the most time was spent. I used this technique for finding candidates for inlining and other optimizations. By profiling the main classes first, I was able to tell which of the sub-classes were in need of optimizing, focusing my effort where it was needed.

Figure 3 *Inlining virtual functions*

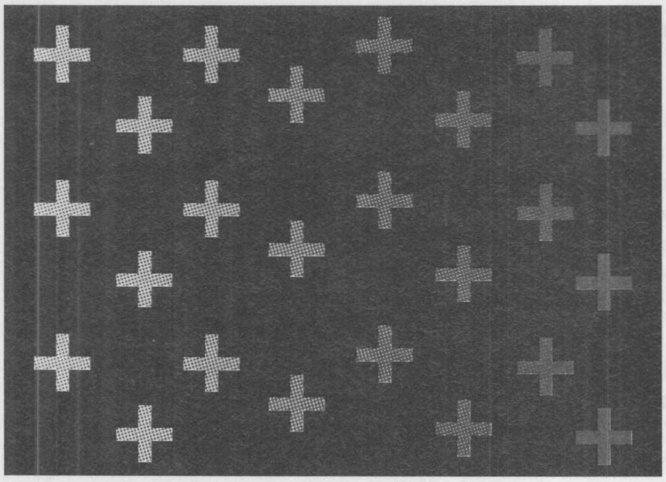
```
class Base {
public:
  virtual void print()
    { printf("Base"); }
};

class Derived1 : public Base {
public:
  virtual void print()
    {
// Base::print() can be inlined
      Base::print();
      printf("Derived1");
    }
};

class Derived2 : public Base {
public:
  virtual void print()
    {
// Base::print() can be inlined
      Base::print();
      printf("Derived2");
    }
};

void function(Base *bp)
{
// Doesn't know whether
// to call Derived1::print()
// or Derived2::print(),
// won't inline:
  bp->print();

// Forced to call Base::print(),
// can inline:
  bp->Base::print();
  Derived1 d1o;
// Forced to call
// Derived1::print(), can
// inline:
  d1o.print();
}

// End of File
```

There are some limitations on inlining virtual functions. If a virtual function is called via a pointer or reference to an object, the actual function that gets called depends on the original type of that object. The compiler cannot determine at compile time the correct function, and therefore it cannot inline it. Virtual functions that are called via an actual object, or ones that are explicitly called with the `::` operator, can be inlined (see Figure 3). In at least one case we changed a virtual function to a non-virtual function in order to take advantage of inlining. This step must be taken with caution, however, possibly adjusting for any change in functionality.

The decision to inline doesn't need to be all or nothing for a function. There might be a situation where a function can be split apart to facilitate inlining. Figure 4 shows that the member function `GetWidgetPointer` gets called 10,000 times, but only has to create a `Widget` 10 times. By splitting this function in two, the part that gets executed 10,000 times can be inlined, and the main part of the code can be isolated in a private member function.

Some special precautions should be taken when inlining constructors and destructors. The compiler may add code that you didn't call explicitly. For example with an inline constructor, the compiler will also inline for you the setting of the virtual table pointer, calls to any base class constructors, and calls to constructors of any data members that have constructors. Borland C++ also adds code to check if the constructor is called on the behalf of a `new` statement and optionally calls a memory allocation routine. The destructors will do the same.

One more precaution for inlines, if the inline contains a function call, that function call may also be inline, which may also contain an inline function, and so on. Make sure you know what you put inline. Just as an aside, some current compilers forget to call the destructors for local variables in inline functions. This is important if the local variables hold memory or system resources and can cause a memory leak. For now I wouldn't create local variables or pass-by-value user-defined objects in an inline function.



Pointer Tricks

One of the best ways to address rampant free-store allocation is by counting pointers. This is a simple but effective technique that can be used on any class to speed up assignments and passing by value. It is best targeted at utility classes that are used in many different places and cannot be isolated.

A good example is a string class. I pointed out above that a class always allocating its own memory can lead to excessive memory allocation and copying. But if the string class contains a pointer to an intermediate data structure with a count, assignment becomes a simple matter of decrementing and incrementing a counter (see Figure 5).

By adding a little smarts to the string class we can reduce the amount of work done, but we don't have to change the external appearance of the class. It is important to maintain the external appearance if you need to change the class, but don't want to make changes to all modules that use the class.

One problem still remains. If you assign `string1` to `string2`, then modify `string1`, `string2` will also get modified. This problem is solved by using "copy-on-write" semantics. Copy-on-write is a strategy where any member function of the string class that modifies the string will first call a function that splits off a private copy of the internal implementation (see Figure 6).

In our application we use both pointer counting and pointer counting with copy on write. The class `BMOIterator` mentioned above uses pointer counting as a smart pointer. Besides constructors, assignment operators, and a destructor, the only member function is the overloaded `operator->`. An object used with this operator appears as simply a pointer (see Figure 7). In order to work intuitively as a pointer, we did not implement copy on write. Also, since a `BMOIterator` holds system resources, we judged it best that no copying should take place unless explicitly asked for.

In another class, `AttributeList`, which is basically a list of integers, we did implement copy on write. Since these `AttributeLists` are not often modified, adding copy on write doesn't add significantly to run time. However after running the `AttributeList` code

Figure 4 *Efficient inlining*

```
Figure 4a. Splitting functions to facilitate inlining.

5.1274 10000 Widget *WidgetHome::GetWidgetPointer()
             {
1.0333 10000   if(widgetPtr == NULL)
               {
0.0012 10        widgetPtr = new Widget;
0.0013 10        if(widgetPtr == NULL ||
                     widgetPtr->isError())
0.0000 0           return NULL;
               }
1.0237 10000    return widgetPtr;
3.5429 10000 }

Figure 4b.  Inlining only the part called most often.

             // the inline doesn't show up on the profile count:

             inline Widget *WidgetHome::GetWidgetPointer()
             {
               return widgetPtr ?
                 widgetPtr :
                 PrivateGetWidgetPointer();
             }

0.0020 10    Widget *WidgetHome::PrivateGetWidgetPointer();
             {
0.0059 10      widgetPtr = new Widget;
0.0035 10      if(widgetPtr == NULL ||
                   widgetPtr->isError())
0.0000 0         return NULL;
0.0008 10      return widgetPtr;
0.0001 10    }

// End of File
```

Listing 2 *Memory pool member functions*

```
#include "mempool.h"

MemoryPoolLink::
  MemoryPoolLink(
    size_t size,
    MemoryPoolLink *_next)
  : bits(0l),
    data(new
      char[size*PoolSize]),
    next(_next)
{
  ;
}

MemoryPoolLink::
  ~MemoryPoolLink()
{
  delete[] data;
}
```

Figure 5 *Counting pointers*

```
class String {
private:
  struct StringImp {
    char *ptr;
    unsigned count;
    StringImp(const char *str)
      : ptr(strdup(str)),
        count(1)
    {
      ;
    }
    ~StringImp()
    {
      delete[] ptr;
    }
  } *imp;
public:
  String(const char *str)
  {
    imp = new StringImp(str);
  }
  String(const String &str)
  {
    imp = str.imp;
    imp->count++;
  }
// assignment is a little tricky
  String &
  operator=(const String &str)
  {
// increment first in case
// of assignment to self
    str.imp->count++;
// be sure to clean up the old imp!
    if(--imp->count == 0)
      delete imp;
    imp = str.imp;
    return *this;
  }
  ~String()
  {
    if(--imp->count == 0)
      delete imp;
  }
};
// End of File
```

Figure 6 *Implementing copy on write*

```
class String {
 // the contents of the string
 // class from Figure 5.

 ...

 // this indexing operator could
 // modify the string
  char &operator[](int i)
  {
    if(imp->count > 1)
      Split();
    return imp->ptr[i];
  }
 // This indexing operator won't
 // modify, don't split.
  char operator[](int i) const
  {
    return imp->ptr[i];
  }
private:
  void Split()
  {
 // Create private copy:
    imp->count--;
    imp = new
      StringImp(imp->ptr);
  }
};
// End of File
```

Figure 7 *Implementing smart pointers*

```
class BMOIteratorImp;

class BMOIterator {
public:
  BMOIterator(const char *dbname);
  BMOIterator(const BMOIterator &);
  BMOIterator &
  operator=(const BMOIterator &);
  ~BMOIterator();
  BMOIteratorImp *operator->()
  {
    return imp;
  }
private:
  BMOIteratorImp *imp;
}

function()
{
  BMOIterator it("DBNAME");
// AddCol is a memeber of
// BMOIteratorImp
  it->AddCol("table.col1");
}

// End of File
```

being created, and much time being spent allocating arrays of zero length. To alleviate this situation, we established a special case where a zero-length list was represented by a null implementation pointer (see Figure 8.). Copying and assignment are slightly longer but the default constructor is simplified. Only after using the profiler did we become aware of this special case optimization.

Overloading *new* and *delete*

Another strategy for addressing memory allocation bottlenecks is to overload the *new* and *delete* operators for a class. Using a special purpose memory allocation algorithm rather than the general purpose using a different heap for different allocation sizes you can reduce the amount of time needed to search for a chunk of free memory, and reduce fragmentation as well.

An example of this is presented in Listings 1 - 3, which implement a memory-pool class and a linked list class that uses the memory pool. The memory-pool class is a heap for a specific size allocation. It is used by associating one instance of the memory pool class with any class (via a static data member) and overloading the *new* and *delete* operators to use the pool. Since the specific *new* operator is only used for that class member, the size is always the same.

The heap works by allocating 32 objects at a time, and maintaining a bit map and the other for chunks that are completely used up. Therefore the allocation logic has to search only one chunk for a free spot. (I have to thank my brother Mark for the bit searching method, without which this method was actually slower than the built-in *malloc*.) This special version of *new* could also be rewritten in assembly language for even greater speed.

For classes that hold limited resources (such as our *BMOJoin* which controls one or more network sockets), a good strategy is to delay creation until the last possible moment. We used code similar to that in Figure 4b inside the *BMOIterator*, calling *GetJoinPointer* rather than accessing the *BMOJoin* pointer itself. In this way we can create *BMOIterators* as we put up a window, but the *BMOJoin* isn't created until a

Figure 8 *Using a special case for an empty list*

```
class AttributeList {
private:
   struct AttributeListImp {
      int *list;
      unsigned count;
      AttributeListImp(int *
         data, unsigned size)
      {
         list = new int[size];
         memcpy(list,data,
            sizeof(int)*size);
         count = 1;
      }
   } *ptr;
public:
   AttributeList()
   {
// Empty list special case:
      ptr = NULL;
   }
   AttributeList(int *data,
      unsigned size)
   {
      ptr = new
         AttributeListImp(data,
           size);
   }
   AttributeList(const
      AttributeList &a)
   {
// Now we have to check
// for null:
      ptr = a.ptr;
      if(ptr) ptr->count++;
   }

   ...

};

// End of File
```

Figure 9 *Delaying creation of an object by restricting access*

```
class BMOJoin;

class BMOIteratorImp {
public:
   BMOIteratorImp()
   {
      itsJoinPtr = NULL;
   }
   ~BMOIteratorImp()
   {
      delete itsJoinPtr;
   }
   int Search(char *str)
   {
      return
        GetJoinPointer()->Search(str);
   }
   void Disconnect()
   {
      delete itsJoinPtr;
      itsJoinPtr = NULL;
   }
private:
   // this is actually split apart
   // (see Figure 4.)
   BMOJoin *GetJoinPointer()
   {
      if(itsJoinPtr)
        return itsJoinPtr;
      itsJoinPtr = new
        BMOJoin(itsStoredParameters);
      if(itsJoinPtr == NULL)
   // for now throw is just an inline
   //for exit()
        throw(ErrNoMem);
      return itsJoinPtr;
   }
};

// End of File
```

Listing 2 *continued*

```
void *MemoryPoolLink::malloc(
   size_t size)
{
static char lookup[] = {
   0,     1,     0,     2,
   0,     1,     0,     3,
   0,     1,     0,     2,
   0,     1,     0,     4,
   };
   int shift = 0;
   unsigned long b = bits;
   if((b&0xFFFF) == 0xFFFF)
   {
     shift = 16;
     b >>= 16;
   }
   if((b&0xFF) == 0xFF)
   {
     shift += 8;
     b >>= 8;
   }
   if((b&0xF) == 0xF)
   {
     shift += 4;
     b >>= 4;
   }
   shift += lookup[b&0xF];
   bits |= (1l << shift);
   return data +
     (shift * size);
}

void MemoryPoolLink::free(
   void *ptr,
   size_t size)
{
   bits &=
     ~(1l <<
     ((char *)ptr-data)/size);
}
```

Listing 2 *continued*

```
MemoryPool::MemoryPool(
  size_t _size)
  : size(_size),
    freeHead(0,NULL),
    usedHead(0,NULL)
  {
  }

void *MemoryPool::add()
  {
  MemoryPoolLink *temp = new
    MemoryPoolLink(size,
    freeHead.next);
  if(temp == NULL)
    return NULL;
  freeHead.next = temp;
  return
    freeHead.next->
    malloc(size);
  }

void *MemoryPool::malloc()
  {
  if(freeHead.next)
    {
    void *ret =
      freeHead.next->
      malloc(size);
    if(freeHead.next->bits ==
      0xFFFFFFFFL)
      {
      MemoryPoolLink *temp =
        freeHead.next;
      freeHead.next =
        temp->next;
      temp->next =
        usedHead.next;
      usedHead.next = temp;
      }
    return ret;
    }
  return add();
  }

void MemoryPool::free(
  void *ptr)
  {
  MemoryPoolLink *temp =
    freeHead.next;
  MemoryPoolLink *prev =
    &freeHead;
  while(temp)
    {
    ptrdiff_t diff =
      temp->data -
      (char *)ptr;
    if(diff > 0 &&
      diff < size*PoolSize)
      {
      temp->free(ptr, size);
      if(temp->bits == 0l)
        {
        prev->next =
          temp->next;
        delete temp;
        }
      return;
      }
    prev = temp;
```

Listing 2 *continued*

```
    temp = temp->next;
    }
  temp = usedHead.next;
  prev = &usedHead;
  while(temp)
    {
    ptrdiff_t diff =
      temp->data -
      (char *)ptr;
    if(diff > 0 &&
      diff < size*PoolSize)
      {
      temp->free(ptr, size);
      prev->next =
        temp->next;
      temp->next =
        freeHead.next;
      freeHead.next =
        temp;
      return;
      }
    prev = temp;
    temp = temp->next;
    }
  }

// End of File
```

Listing 3 *A linked list for the memory pool*

```
#include "mempool.h"
#include <fstream.h>
#include <string.h>

class Link
  char *data;
  Link *next;
  static MemoryPool pool;
public:
  friend class List;
  friend class Iterator;
  Link(const char *_data,
    Link *_next)
    {
    next = _next;
    data = strcpy(new
      char[strlen(_data)+1],
      _data);
    }
  ~Link()
    {
    delete data;
    }
  void *
    operator new(size_t)
    {
    return pool.malloc();
    }
  void
    operator delete(void *ptr)
    {
    pool.free(ptr);
    }
};
```

Listing 3 *continued*

```
MemoryPool
Link::pool(sizeof(Link));

class List {
  Link head;
public:
  friend class Iterator;
  List ();
  ~List();
  void add(char *data);
};

class Iterator {
  Link *link;
public:
  Iterator(List &_list)
    {
    link = _list.head.next;
    }
  char *Next()
    {
    char *ret = link ?
      link->data : NULL;
    link = link->next;
    return ret;
    }
};

List::List()
  : head("",NULL)
{
  ;
}

List::~List()
{
  while(head.next)
  {
    Link *temp =
      head.next->next;
    delete head.next;
    head.next = temp;
  }
}

void List::add(char *data)
{
  head.next = new
    Link(data,head.next);
}

main(int, char **argv)
{
static char buff[1024];
  List list;
  ifstream in(argv[1]);
  while(in.getline(buff,
    sizeof(buff)))
    list.add(buff);
  Iterator it(list);
  char *ptr;
  while((ptr = it.Next()) !=
    NULL)
    cout << ptr << endl;
}

// End of File
```

search is performed. We added a member function called *Disconnect* to the *BMOIterator*, and call it when a window is put into the background to delete the *BMOJoin* pointer and free resources for the foreground window (see Figure 9).

Figure 10 *Going low-level to improve efficiency*

```
Figure 10a. Results of an inefficient += operator.

  1.0235    500  void PadWithSpaces(CString &str, int count)
                 {
  5.0346  20000     while(count--)
 30.0397  19000       str += " ";
  1.4354    500  }

Figure 10b. Improved performance with low-level C-strings.

  1.0233    500  void PadWithSpaces(CString &str, int count)
                 {
  2.4505    500     char *tmp = new char[count+1];
  3.2930    500     memset(tmp,' ',count);
  0.9438    500     tmp[count] = '\0';
  5.3049    500     str += tmp;
  1.9430    500     delete[] tmp;
  1.4353    500  }

// End of File
```

Conclusion

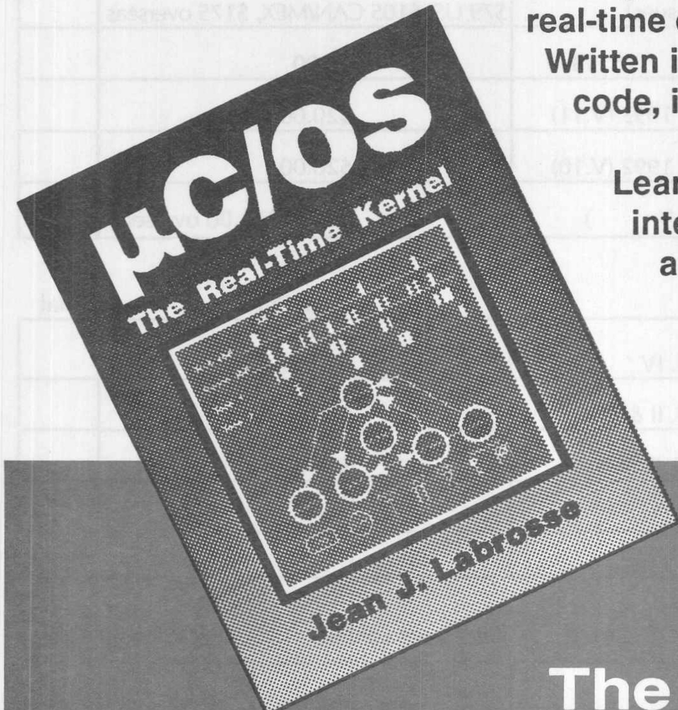
Finally, running the profiler through a particularly sluggish area, we discovered that a lot of time was being spent padding strings with spaces. The problem here was that *operator+=* for the string was not as efficient as we had hoped. By going to a lower level, and accessing C-style strings directly, we managed to speed up the padding process considerably.

I should mention that a good string class would have had a padding function, or at least the ability to create a blank string of count bytes. This low-level access then wouldn't be necessary. Since the string class was part of a commercial library we didn't want to modify or add to it. It's good to know that all the old C tricks are available even if just used at the lowest levels. Credit has to be given here to the profiler for finding this bottleneck.

Many of the optimizations described above are fairly simple because of the separation of interface from implementation. The idea is to be able to grease up a class without having to worry about side effects that might be possible in a less restrictive interface. Other optimizations are possible by dipping into C++'s C heritage as a low-level language.

Of course there is no substitute for a good design effort up front. A temptation in design is to make a lot of "friendly" classes, which access each other's internals. But what you wind up with is "spaghetti objects." By maintaining integrity between classes, you can twiddle with the internal bits to your heart's content without having to worry about unforeseen side effects. □

Push the Limits of Real-time Design!



Investigate the fundamentals of building real-time embedded kernels with µC/OS. Written in C with minimum assembly code, it is portable and ROM able.

Learn about task priority scheduling, intertask communication, interrupts, and performance benchmarking.

µC/OS is complete preemptive multitasking operating system that handles 63 tasks.

µC/OS
The Real Time Kernel
by Jean J. Labrosse

Secrets of Embedded Systems Revealed!

- Performance compares to commercial kernels
- Written in C with assembly code minimized
- Assembly code minimized for easy portability
- Includes System Code & Users Manual

Companion Disk for $24.95

Only $29.95 plus shipping

Order Today!

R&D publications, inc.

(order book W60, book & disk W62)

913-841-1631

FAX 913-841-2624

VISA MasterCard

✧ Request 127 on Reader Service Card ✧

The C Users Order Form

	Quantity	Code #	Item	Unit Price	Total
C Users Journal			1-year subscription (12 issues)	$29.95 US, $46 CAN/MEX, $65 overseas	
			2-year subscription (24 issues)	$56 US, $76 CAN/MEX, $123 overseas	
			3-year subscription (36 issues)	$79 US, $105 CAN/MEX, $175 overseas	
			Magazine Code Disk (Mo: Yr:)	$5.00	
			Magazine Code Disks — 1993 (V.11)	$20.00	
			Magazine Code Disks — 1992 (V.10)	$20.00	
			CUJ Back Issue (Mo: Yr:)	$7.50, $11.00 overseas	

	Quantity	Code #	Title	Unit Price	Total
Books See below for overseas shipping charges.		CAT4	The CUG Directory - Vol. IV	$10.00	
		CAT23	The CUG Directory - Vol. II & III	$18.00	
		CAT24	CUG Directory Volumes I, II, III & IV	$28.00	

	Quantity	Code #	Disk Format/Size (MS-DOS, etc.)	# disks per volume	Unit Price	Total
Disks See below for overseas shipping charges. NOTE: Please indicate format and size of disks ordered.				( ) x $4.00		
				( ) x $4.00		
				( ) x $4.00		
				( ) x $4.00		

Please send more information about:

- ☐ Sys Admin
- ☐ The C Users Journal
- ☐ The C Users Bookstore
- ☐ Windows/DOS
- ☐ The C Users' Group

OVERSEAS SHIPPING	BOOKS - Add 45% + $3.50 s&h	
	DISKS - Add 30% + $3.50 s&h	
shipping charge in North America ($3.50)		
TOTAL		

All payments must be in US dollars (Mastercard/VISA accepted)
NOTE: Call 913-841-1631 for special shipping!

Name ____________

Company ____________

Address ____________

City ____________

State ______ Zip Code ______

Country ____________

Daytime Phone ____________

☐ I am a current subscriber

☐ MC ☐ Visa Expiration Date ______

Card # ____________

Signature ____________

Mail to: The C Users Journal, 1601 W. 23rd St., Suite 200, Lawrence KS 66046-2743, (913) 841-1631
— For fastest service, FAX (913) 841-2624 —

The C Users' Group collects and maintains the public domain C source code and shareware listed below. ***Distribution fee is $4.00 per disk.*** *There is a $3.50 shipping and handling charge per order U.S.; 30% overseas. If there are multiple disks in a volume, that number is indicated in parentheses. Due to updates,* ***the number of disks per volume is subject to change without notice.*** *The CUG Library supports code written for MS-DOS. Be sure to specify size when ordering disk ($3\frac{1}{2}$" or $5\frac{1}{4}$"). Volumes are continually added.*

For volumes 101-277 see the CUG Library Directories.

Artificial Intelligence

299—MEL and BP
297—Small Prolog *(2)*
396—NNUTILS

Assemblers and Disassemblers

398—ASxxxx Cross Assembler - Part 3
363—68020—Cross Assembler *(2)*
348—8048—Disassembler/Z80—Assembler
346—ASxxxx Cross Assembler - Part 2 *(2)*
338—68000—C compiler and assembler *(2)*
335—Frankenstein Cross Assemblers *(4)*
316—AS8—Cross Assembler
303—MC68K Disassembler
292—ASxxx Cross Assembler - Part 1 *(4)*

Communications

380—JMODEM
314—MNP C Library
308—MSU, REMZ & LIST *(2)*
307—ADU & COMX

Compilers & Interpreters

359—GNU C/C++ 386—exec and lib. source *(12)*
338—68000—C Compiler and Assembler *(2)*
309—6809—C Compiler for MS-DOS

File management

387—C/C++ Lost Algorithms
386—Thomson-Davis Editor
382—GZIP
379—ZOO
377—DSR Functions
367—GNU File and Text Utilities for MS-DOS *(2)*
358—cbase
347—TAVL Tree
342—I8255—Interface Library
329—UNIX Tools for PC *(2)*
326—SoftC Database Library *(3)*
311—DB Package
308—MSU, REMZ & LIST *(2)*

Forms management

340—C-Window
337—Designing Screen Interfaces in C
332—PC curses *(2)*
327—Panels for C *(2)*
301—BGI Applications *(2)*
281—Unicorn Library v5.1 *(2)*

Function libraries

394—C++SIM
395—Input-Edit, SORTLIST AVL, and Typing Tutor
393—LL, GIFSave, and Cordic++
390 Another C Tools Lib—ACTLIB
385—BCC+ Coroutines
384—Ghostscript *(13)*
372—Mouse++, String++ and Z++ classes
376—OS/2—Tools *(4)*
368—GNUlib for MS-DOS
361—Gadgets and Term
352—String and Vlist
342—I8255—Interface Library
339—CTRLCLIB *(2)*
321—Mouse Trap Library
309—6809—C Compiler for MS-DOS
302—3-D Transforms
300—MAT_LIB
295—blkio Library

Games

344—C Grabbag #1 *(2)*
332—PC Curses *(2)*
323—Fireworks and Adventure
305—HGA Mandelbrot Explorer and Card Games *(2)*
301—BGI Applications *(2)*

Graphics

393—LL, GIFSave, and Cordic++
389 VGA FontLib, Make Font & DXF viewer
383—VGL *(2)*
381—JPEG
350—PCX Graphics Library
343—C Image Processing System *(3)*
336—EGAPAL/EDIPAL
334—GNUPLOT
325—VGA Graphics Library *(2)*
323—Fireworks and Adventure
321—Mouse Trap Library
320—Convolution Image Process
317—Group 3—Image Processing
315—FTGRAPH (Fast-Fourier Transform Graphics)
305—HGA Mandelbrot Explorer and Card Games *(2)*
302—3-D Transforms
301—BGI Applications *(2)*
293—& CUG294—3D Medical Imaging *(6)*
287—GRAD for MSC C *(2)*
286—GRAD for Turbo C *(3)*

Language Tools & Other Languages

391—C/C++ Exploration Tools v2.12
376—OS/2—Tools *(4)*
369—Genitor *(3)*
370—GATool *(2)*
364—C-ACROSS *(2)*
356—Serlock for Macintosh *(3)*
355—Sherlock for MS-DOS *(3)*
357—CSTAR *(2)*
345—TLC/TLP
344—C Grabbag #1 *(2)*
333—gAWK *(2)*
329—UNIX Tools for PC *(2)*
322—Doctor's Tools
319—CPP (C preprocessor) *(2)*
311—Make-Maker
310—Little Smalltalk for MS-DOS *(2)*
299—MEL and BP
297—Small Prolog *(2)*
296—C to C++ Migrator
290—FLEX *(2)*
285—BISON for MS-DOS *(3)*

Math & Scientific Applications

391—C/C++ Exploration Tools v2.12
378—NEWMAT
369—Genitor *(3)*
370—GATool *(2)*
344—C Grabbag #1 *(2)*
341—Orbit Propagation
315—FTGRAPH (Fast-Fourier Transform)
308—MSU, REMZ & LIST *(2)*
306—Thread and Synapsys
305—HGA Mandelbrot Explorer and Card Games *(2)*
301—BGI Applications *(2)*
300—MAT_LIB
299—MEL and BP

Multitasking

387—C/C++ Lost Algorithms
385—BCC+ Coroutines
362—RMAXTask
330—CTask *(3)*
306—Thread and Synapsys

Screen managers

340—C-Window
337—Designing Screen Interfaces in C
328—WTWG *(2)*
327—Panels for C *(2)*
324—WGCONIO
321—Mouse Trap Library
301—BGI Applications *(2)*
298—PC Curses
291—JJb For Quick C and Turbo C Programmers
283—FAFNIR *(3)*

Simulations

394—C++SIM
349—Simulation Subroutine Set
308—MSU, REMZ & LIST *(2)*
306—Thread and Synapsys

Text processing tools

399—MINED Editor
395—Input-Edit, SORTLIST AVL, and Typing Tutor
392—GNU Indent v1.8
388—Anthony's Tools
386—Thomson-Davis Editor
374—MicroSpell v2.0
373—MicroEMACS for Windows *(2)*
367—GNU File and Text Utilities for MS-DOS *(2)*
366—MicroEMACS Update *(3)*
365—Elvis *(3)*
360—Uspell *(2)*
344—C Grabbag #1 *(2)*
331—SE Editor
324—WGCONIO
318—RED *(2)*
313—STEVIE
304—ROFF5

Tutorials

397—International Obfuscated C Code Contest 1984-1993
396—NNUTILS
395—Input-Edit, SORTLIST AVL, and Typing Tutor
353—C++ Tutor *(2)*
257—& CUG258—C TUTOR FOR TURBO C
252—& CUG253—C TUTOR

Utilities

391—C/C++ Exploration Tools v2.12
390 Another C Tools Lib—ACTLIB
388—Anthony's Tools
387—C/C++ Lost Algorithms
382—GZIP
379—ZOO
377—DSR Functions
376—OS/2—Tools *(4)*
344—C Grabbag #1 *(2)*
339—CTRLCLIB *(2)*
332—P C curses *(2)*
329—UNIX Tools for PC *(2)*
322—Doctor's Tools
321—Mouse Trap Library
307—ADU and COMX
295—blkio Library

Windowing Packages

388—Anthony's Tools
386—Thomson-Davis Editor
375—TextView
371—Windos IO v 2.0 *(2)*
361—Gadgets and Term
354—CES Mouse Tools Library with JoyStick
351—UltraWin *(2)*
340—C-Window
337—Designing Screen Interfaces in C
332—P C curses *(2)*
328—WTWG *(2)*
327—Panels for C *(2)*
324—WGCONIO
298—PC Curses
283—FAFNIR *(3)*

We can supply all CUG volumes 100 through 364 on CD-ROM. Order R01 for $49.95

The C Users' Group, 1601 W. 23rd St., Suite 200, Lawrence, KS 66046-2700
(913) 841-1631 • FAX (913) 841-2624

Enhancing the UNIX Korn Shell Using Predictor Techniques

Philip Thomas and Shmuel Rotenstreich

Introduction

On most computer systems, users interact with the system through command-language interpreters called shells. These shells accept user input and interpret them as commands for the system. There are three major UNIX shells: Bourne, C and Korn (kshell). Other shells include command.com for MS-DOS and for OS/2.

The Korn Shell, which we consider here, offers sophisticated management of past commands (history). We have enhanced this functionality to include a learning automaton that predicts the next command. This command prediction often allows the user to avoid entering the command sequence in its entirety. In most of the computing environments we considered, this enhanced shell predicted the next command with a high degree of accuracy.

This article describes our shell enhancements and details some of the methods we used to implement them. Although the Korn Shell was our target shell, we have applied these same enhancements to the C Shell. We believe this article will show that our enhancements are applicable to other shells as well.

Attaining Command Cycle Consciousness

In our research we have found that most users exhibit cyclic behavior when interacting with an operating system. For example, to create and execute a program, users may produce the following:

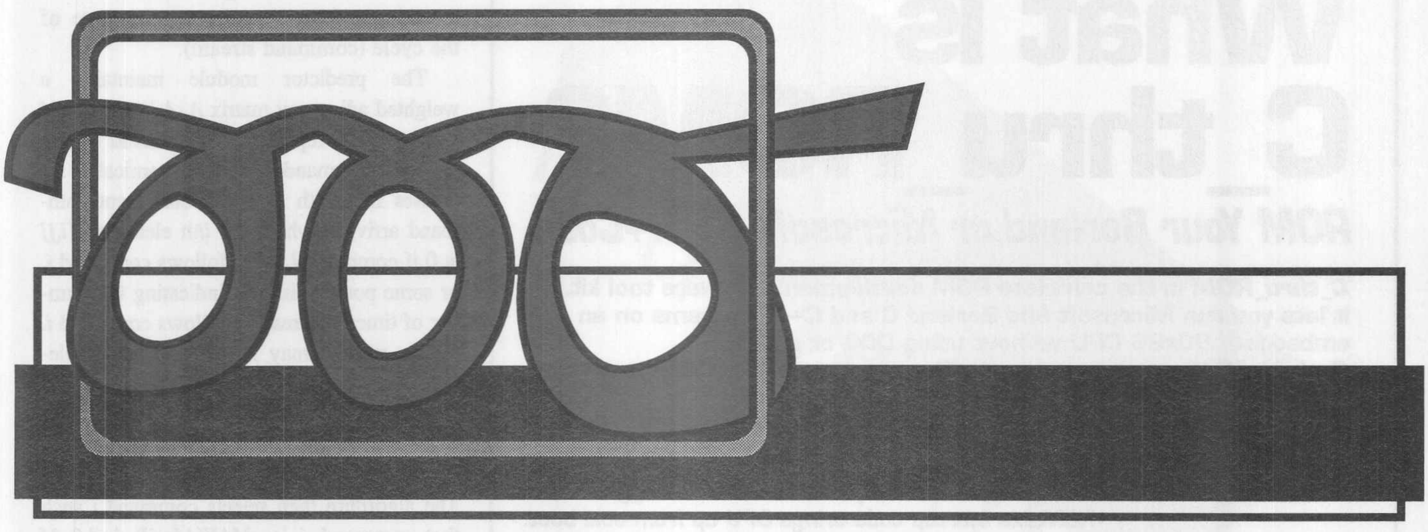
1. Command: Evoke editor — create the source file.
2. Command: Create executable — compile & link the source file.
3. Command: Execute the file created in (2) — examine the results.

The user typically repeats this sequence until he or she has completed and thoroughly debugged the program.

If a shell can recognize such cyclical behavior (we say it has *cycle consciousness*) it can predict the user's next command at any point in the sequence. We incorporate cycle consciousness into the shell by integrating it with the Predictor module outlined in the next section.

The Predictor Module

To incorporate cycle-based knowledge into various operating system facilities, we have developed an abstract data type module called a Predictor (Listing 1). The Predictor is a learning automation representative of the learning-from-analogy class of learning strategies. In learning-from-analogy strategies, the learner reaches a conclusion about the current case by considering previously processed cases bearing strong similarities to the current case. For the predictor module, the previously processed cases are the sequences of commands already encountered from the command stream.



Philip K. Thomas received the B.S. degree in Physics from the California Polytechnic State University and is currently in the process of defending his Ph.D. dissertation in Computer Science at the George Washington University. Philip also serves as Director of System Architecture at PRC corporation in Mclean, Virginia and can be reached at philip@rsi.prc.com.

Shmuel Rotenstreich received the B.S. degree in Computer Science from the Tel Aviv University and the Ph.D. degree also in Computer Science from the University of California at San Diego. Shmuel is currently Professor of Engineering and Applied Sciences at the George Washington University and can be reached at shmuel@sparko.gwu.edu.

Listing 1 *Definition of the Predictor*

```
enum ReturnValue
  {
    Failure,
    Success
  };

const DEF_CARDINAL=500;          //number of commands a_matrix can hold
const DEF_DELTA_CARDINAL=100;    //increment of cardinal_a_matrix
const MAX_SIZE_COMMAND=50;       //maximum size of command

class predictor
  {
        int num_commands;        //current number of unique commands
        int cardinal_a_matrix;   //max number of commands a_matrix can hold
        int *a_matrix;           //pointer to the adjacency matrix
        char *commands;          //list of unique commands
        int last_ordinal;        //index of last command

        ReturnValue size(int cardinality);   //malloc or remalloc to create
                                             // approp. a_matrix & commands
        int is_unique(char *command);        //checks commands[] for command
                                             // <0 =>No,else=>index of command
        ReturnValue insert(char *command);   //add command to commands
        ReturnValue update(int ordinal);     //increment a_matrix entry

    public:
        predictor()
          {
            num_commands=0;
            cardinal_a_matrix=DEF_CARDINAL;
            size(cardinal_a_matrix);
            last_ordinal=-1;
```


The Predictor module incorporates an abstract component as well as several concrete components. The abstract component is the prediction algorithm, which we describe shortly. The concrete components consist of three major classes:

1. Control Class: The two instances of this class supply entry points for initializing and terminating the Predictor Module.
2. Input Class: This class obtains the next command from external modules.
3. Predict Class: This class makes predictions for the Predictor module. `predictor` can make two types of predictions:
   1) The next command
   2) When a particular command will next occur

By creating a `predictor` class, we encapsulate all cycle-dependent code and data, making it easier to modify. This method of encapsulation also permits the coexistence of multiple predictors. (Environments where multiple command streams exist require multiple predictors.) We describe the `predictor` class in detail later in this article.

The Algorithm

For this discussion we say that a command stream C is a sequence of N commands composed of M *unique* commands. These commands arrive at the predictor one at a time via the input interface. These commands determine the current state of the cycle (command stream).

The predictor module maintains a weighted adjacency matrix A. A is an $M \times M$ matrix which represents a command stream C (this command stream dynamically increases in length as each subsequent command arrives), where the ijth element $A[i,j]$ is 0 if command j never follows command i, or some positive integer indicating the number of times command j follows command i. (Some readers may recognize this implementation as part of a *semantic network.*)

To predict the next command, the algorithm locates the corresponding row for the latest command n in the adjacency matrix A. The algorithm then selects command i such that command i is: $MAX(A[n,i])$ $i=1,2..M$ (index of command i) and $A[n,i] > 1$

If such a command exists, the algorithm returns command i as the best prediction of the next command to occur. If no such command exists, the algorithm returns indicating that the predictor module cannot predict the next command given its current state.

Listing 1 *continued*

```
    }
    predictor(int cardinality) //overload constructor
    {
        num_commands=0;
        cardinal_a_matrix=cardinality;
        size(cardinal_a_matrix);
        last_ordinal=-1;
    }
    ~predictor()        //destructor
    {
        cardinal_a_matrix=0;
        free(a_matrix);
        free(commands);
    }

    ReturnValue PutNextCommand(char *);
    ReturnValue GetNextCommand(char *);
    int WhenNextCommand(char *);
};

ReturnValue predictor::PutNextCommand(char *command)
{
    int ordinal;

    if(num_commands+1 >= cardinal_a_matrix) //no space ?
    {
        cardinal_a_matrix+=DEF_DELTA_CARDINAL;
        if(size(cardinal_a_matrix)==Failure)//can not allocate space
            return(Failure);
    }

    if((ordinal=is_unique(command))==-1)    //command encountered before?
    {
        if(insert(command) == Failure)      //no - add it
            return(Failure);
        ordinal=num_commands;               //new ordinal number of command
    }

    return(update(ordinal));                //return appropriate value
}

ReturnValue predictor::GetNextCommand(char *command)
{
    int ordinal,max=0,i;
    int *last_command;

    //note: assumes a_matrix is stored in row major fashion

    last_command=a_matrix+                  //calculate row of last_command
        last_ordinal*
        cardinal_a_matrix*sizeof(int);  //size of a row
    //Note: With certain compilers, sizeof(int) is unnecessary

    for(i=0; i<num_commands; ++i)           //do MAX() function
    {
        if(*(last_command+i*sizeof(int))>max)
        {
            max=*(last_command+i*sizeof(int));
            ordinal=i;
        }
    }
    if(max>0)
    {
        strcpy(command,commands*MAX_SIZE_COMMAND);
        return(Success);
    }
    else
    {
        command=NULL;
        return(Failure);
    }
```

Listing 1 *continued*

```
}

int predictor::WhenNextCommand(char *command)
{
  int count=1;
  int old_last_ordinal=last_ordinal;  //save state of predictor
  int any_cycle[num_commands];        //check to see if we have cycled
  int i;
  char pcommand[MAX_SIZE_COMMAND];

  //zero
  for(i=0; i<num_commands; ++i)
    any_cycle[i]=0;

  while(GetNextCommand(command)==Success)
   {
     if(!strcmp(pcommand,command))   //found the command
        break;

     i=is_unique(pcommand);          //find index of predicted command
     if(!any_cyle[i]^1)              //test and check
     {
        count=0;                     //we have cycled - failure
        break;
     }

     ++count;
   }
  return(count);
}

/* End of File */
```

The algorithm performs the following steps to predict *when* a particular command will next occur:

1. Save the current state of the predictor module.
2. Set *count=0.*
3. Call the predict-the-next-command interface repeatedly until the return value command *i* is
   a) Equal to the specified command
   b) A value indicating that the predictor cannot make a prediction
   c) A value previously returned by the predict-the-next-command interface (this implies that the predictor assumes the command stream will cycle without an occurrence of the specified command). For each time the predict-the-next-command interface is called, increment *count.*
4. Restore the original state of the predictor module.
5. Return *count* if step 3 terminated because of condition 3.a, otherwise return a value indicating that the predictor cannot predicting when the specified command will next occur.

The *Predictor* Class

The `predictor` class contains three publicly accessible functions to perform input and output:

`PutNextCommand` — This function registers commands occurring on the system. We modified the main control loop of the kshell to call this function whenever the kshell assembled a command and registered it to provide "history" functionality. This function returns values corresponding to internal fatal errors and success.

`GetNextCommand` — This function passes the next predicted command to the system, if it can be predicted. We augmented the kshell source to recognize when the user types ESC-p (in emacs mode) at the prompt, and to call *GetNextCommand.* As a result, the kshell produces either a beep (to indicate the inability to predict the next command) or a command string adjacent to the prompt, which the user may execute by typing a carriage return.

`WhenNextCommand` — As its name implies, this function predicts when a particular command will occur. We do not use this function in the kshell. We have

included it in the *predictor* module because it is invaluable in other systems that require this kind of prediction. (e.g. in a file caching system — when a file needs "flushing," information about when a file will next be used is advantageous.) This function returns zero to indicate that the command stream will cycle before it encounters the specified command. This function returns a value of less than zero to signal an internal error.

These last two functions maintain and manipulate the adjacency matrix mentioned previously.

Results

To show how well the predictor works, we have derived the following examples from a command stream in a programming environment. Figure 1 shows the first example. The first column shows the actual command stream. The second column, with the prefix *p:* shows the predicted command stream. The last two columns show the current percentile of successful predictions and the maximum percentile of successful predictions, respectively. The second example (Figure 2) differs from the first only by one command; we have removed this command, ls, from the stream in example 2. This command represents an "exception" to the cyclical nature of the command stream. Thus, example 2 shows the effect of filtering out exceptions.

Open Issues:

To keep this article consice several items have not been sufficiently developed. The following are a few points that we believe require further clarification.

How are command parameters handled?

Commands can be classified as either tightly coupled or loosely coupled with their parameters. The degree of coupling is context dependent. For instance, when the predictor is used in a file caching subsystem, predicting the sequence of parameters (e.g. file names) is more important than predicting the sequence of the commands themselves. We say the commands are loosely coupled. In the case of tightly coupled commands, we treat parameters and their commands as one predictor unit, that is, the predictor considers the same command with different parameters

Anatomy of a Command Shell

In most systems, user programs and system programs are executed by the command-language interpreter. In more sophisticated systems such as UNIX, there are no major distinctions between this interpreter and any other program — so users can easily create their own shells.

The shell actually executes a command by completing a *fork*, after which the child process executes an *execve* (load and execute) of the command. The parent process (the shell) does a *wait* and suspends its own execution until the child process finishes executing and performs an *exit*. In multi-tasking systems, such as UNIX, both the shell and the command it is processing can execute concurrently. Users can initiate concurrent execution by typing a command followed by an ampersand. The shell interprets this symbol as an indication not to perform the *wait*; instead the shell continues with the next step in its command input by prompting the user for the next command.

This capability implies the existence of a fairly sophisticated interprocess communication system. As a bare minimum, a child process needs a method to signal its termination to the parent process (the shell), which is not necessarily polling for this signal. □

command streams

```
Example 1:
==========
Original Command Stream Predicted Command Stream
----------------------- ------------------------ ---  ---
o:cc -o timer timer.c  p:                        00%  00%
o:timer                p:                        00%  00%
o:ls -l timer          p:                        00%  00%
***Removed from example 2****
o:vi timer.c           p:                        00%  00%
o:cc -o timer timer.c  p:cc -o timer timer.c    *16%  16%
o:timer                p:timer                  *28%  28%
o:vi timer.c           p:ls -l timer             25%  28%
o:vi tstin             p:cc -o timer timer.c     22%  28%
o:cc -o timer timer.c  p:                        20%  28%
o:vi tstin             p:timer                   18%  28%
o:vi timer.c           p:cc -o timer timer.c     16%  28%
o:cc -o timer timer.c  p:cc -o timer timer.c    *23%  28%
o:timer                p:timer                  *28%  28%
o:vi timer.c           p:vi timer.c             *33%  33%
o:cc -o timer timer.c  p:cc -o timer timer.c    *37%  37%
o:timer                p:timer                  *41%  41%
o:vi timer.c           p:vi timer.c             *44%  44%
o:cc -o timer timer.c  p:cc -o timer timer.c    *47%  47%
o:timer                p:timer                  *50%  50%
o:vi timer.c           p:vi timer.c             *52%  52%
o:cc -o timer timer.c  p:cc -o timer timer.c    *54%  54%
o:timer                p:timer                  *56%  56%
o:vi timer.c           p:vi timer.c             *58%  58%
o:cc -o timer timer.c  p:cc -o timer timer.c    *60%  60%
o:timer                p:timer                  *61%  61%
o:vi timer.c           p:vi timer.c             *62%  62%
o:cc -o timer timer.c  p:cc -o timer timer.c    *64%  64%
```

either parse the parameters out and use them as distinct predictor units, or, as is usually more beneficial, we still treat command-parameter sets as tightly coupled and treat them as single predictor units.

Are command cycles common?

Yes. When we remove a lot of the "noise" from command streams, we find that most of the commands are members of command cycles. The "noise," we have discovered, comes in many forms. Many command streams are sprinkled with commands we isolate as "exceptions." These exceptions would be commands like ls, dir, who etc. Users tend to use commands like these with enough randomness that it is easy to filter these commands out of otherwise perfectly healthy command streams. Another form of noise is the partial cycle. The partial cycle is best illustrated using the example session. In the edit-compile-execute cycle mentioned above, evoking the compiler sometimes results in errors that require the user to re-visit the editor without completing the cycle. Partial cycles are much harder to deal with than exceptions and, consequently, our success rate with these tends to be lower.

GUI Environments

We have also begun investigations into incorporating cycle consciousness into graphical user interface (GUI) environments.

Patching the Korn Shell

The kshell source we started with was PD KornShell written by Eric Gisin *<egisin@math.UWaterloo.EDU>*. PD Korn Shell installs on 4.2+ BSD System V, and POSIX-compatible systems. PD KornShell assumes you have Standard C (ANSI) and POSIX header files and functions. The PD KornShell source is available on several Internet locations including:

ftp.uu.net (192.48.96.9)
/usenet/comp.sources.amiga/volume91/shells and
softu1.ncu.edu.tw (140.115.19.11)
/pub5/tarz

We assembled the kshell on an HP-UX machine using HP's C++ compiler. On the HP-UX system, which is a hybrid UNIX system (System V & BSD), only a negligible amount of source modification was needed to get the shell up and running. Since the source was in "public-domain UNIX-type" C, we decided to leave the original parts in C and incorporate our enhancements in a C++ class. To facilitate the intermingling of C and C++, we instructed the C++ compiler to suppress name mangling (See "Using C/C++ with Clipper" by Mark W. Schumann in the December 1993 issue of CUJ for a thorough treatment of name mangling in C++). □

The essential problem here is defining a command primitive. In a command-oriented interface a command primitive is well defined, but in a modern GUI a command primitive is more loosely defined and may incorporate several user actions, such as mouse moves and button clicks. User activity is hard to partition into distinct commands.

Conclusion

As in any article of this nature, we had to summarize a large body of work both theoretical and experimental to present here. The algorithm presented here is a first-degree learning automaton. We have added several filters and general enhancements to this automaton resulting in several different predictors that, depending on the situation, are selected and evoked at run time (late binding — virtual functions). Our work leveraged the `predictor` across

Figure 1 *continued*

```
o:timer                 p:timer                 *65%  65%
o:vi timer.c            p:vi timer.c            *66%  66%
o:cc -o timer timer.c   p:cc -o timer timer.c   *67%  67%
o:timer                 p:timer                 *68%  68%
o:vi timer.c            p:vi timer.c            *69%  69%
o:cc -o timer timer.c   p:cc -o timer timer.c   *70%  70%
o:timer                 p:timer                 *71%  71%
o:vi timer.c            p:vi timer.c            *72%  72%
o:cc -o timer timer.c   p:cc -o timer timer.c   *72%  72%
o:timer                 p:timer                 *73%  73%
o:vi timer.c            p:vi timer.c            *74%  74%
o:cc -o timer timer.c   p:cc -o timer timer.c   *75%  75%
o:timer                 p:timer                 *75%  75%
o:vi timer.c            p:vi timer.c            *76%  76%
o:cc -o timer timer.c   p:cc -o timer timer.c   *76%  76%
o:timer                 p:timer                 *77%  77%
o:vi timer.c            p:vi timer.c            *77%  77%
o:cc -o timer timer.c   p:cc -o timer timer.c   *78%  78%
o:timer                 p:timer                 *78%  78%
o:vi timer.c            p:vi timer.c            *79%  79%
o:timer                 p:cc -o timer timer.c    77%  79%
o:vi timer.c            p:vi timer.c            *78%  79%
o:timer                 p:cc -o timer timer.c    76%  79%
o:vi timer.c            p:vi timer.c            *76%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *77%  79%
o:timer                 p:timer                 *77%  79%
o:vi timer.c            p:vi timer.c            *78%  79%
o:timer                 p:cc -o timer timer.c    76%  79%
o:mail                  p:vi timer.c             75%  79%
o:remsh rigel           p:                       74%  79%
o:vi timer.c            p:                       72%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *73%  79%
o:timer                 p:timer                 *73%  79%
o:vi timer.c            p:vi timer.c            *74%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *74%  79%
o:vi timer.c            p:timer                  73%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *73%  79%
o:more $inc/setjmp.h    p:timer                  72%  79%
o:vi timer.c            p:                       71%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *72%  79%
o:vi timer.c            p:timer                  71%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *71%  79%
o:vi timer.c            p:timer                  70%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *70%  79%
o:timer                 p:timer                 *71%  79%
o:vi timer.c            p:vi timer.c            *71%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *72%  79%
o:timer                 p:timer                 *72%  79%
o:vi timer.c            p:vi timer.c            *72%  79%
o:cc -o timer timer.c   p:cc -o timer timer.c   *73%  79%
o:timer                 p:timer                 *73%  79%
```

several operating-system elements including memory management, schedulings and disk allocation. Overall, we think our assertions for incorporating cycle consciousness have been well founded. We have had favorable results in the areas we have studied. □

References:

Peterson, James L.; Silberschatz, Abraham, *Operating System Concepts*, Addison-Wesley Publishing Co, 1985.

Tanimoto, Steven L., *The Elements of Artificial Intelligence*, Computer Science Press, 1990.

Thomas, Philip K., Rotenstreich, Shmuel, "Command Cycles," Ph.D. Dissertation, George Washington University, 1993.

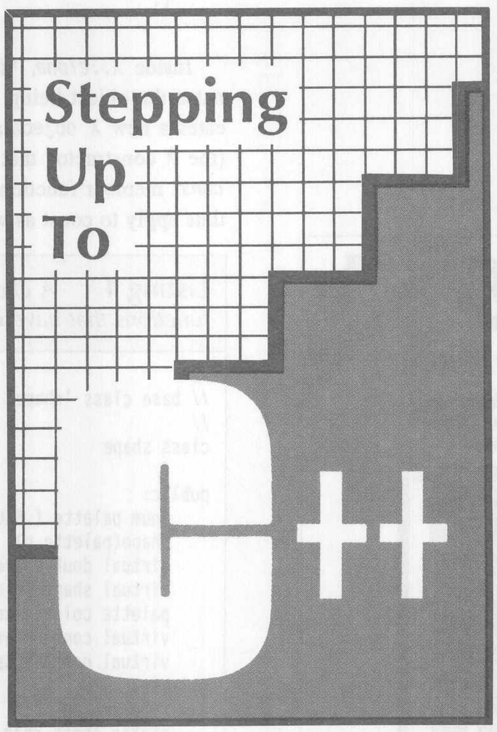
Figure 2 *The sample session with an exception removed*

```
Example 2: (Without ls)
======================
Original Command Stream Predicted Command Stream
------------------------------------------------- ---

o:vi timer.c               p:                       00%  00%
o:cc -o timer timer.c      p:                       00%  00%
o:timer                    p:                       00%  00%
o:vi timer.c               p:                       00%  00%
o:cc -o timer timer.c      p:cc -o timer timer.c   *20%  20%
o:timer                    p:timer                 *33%  33%
o:vi timer.c               p:vi timer.c            *42%  42%
o:vi tstin                 p:cc -o timer timer.c    37%  42%
```


Figure 2 *continued*

```
o:cc -o timer timer.c      p:                       33%  42%
o:vi tstin                 p:timer                  30%  42%
o:vi timer.c               p:cc -o timer timer.c    27%  42%
o:cc -o timer timer.c      p:cc -o timer timer.c   *33%  42%
o:timer                    p:timer                 *38%  42%
o:vi timer.c               p:vi timer.c            *42%  42%
o:cc -o timer timer.c      p:cc -o timer timer.c   *46%  46%
o:timer                    p:timer                 *50%  50%
o:vi timer.c               p:vi timer.c            *52%  52%
o:cc -o timer timer.c      p:cc -o timer timer.c   *55%  55%
o:timer                    p:timer                 *57%  57%
o:vi timer.c               p:vi timer.c            *60%  60%
o:cc -o timer timer.c      p:cc -o timer timer.c   *61%  61%
o:timer                    p:timer                 *63%  63%
o:vi timer.c               p:vi timer.c            *65%  65%
o:cc -o timer timer.c      p:cc -o timer timer.c   *66%  66%
o:timer                    p:timer                 *68%  68%
o:vi timer.c               p:vi timer.c            *69%  69%
o:cc -o timer timer.c      p:cc -o timer timer.c   *70%  70%
o:timer                    p:timer                 *71%  71%
o:vi timer.c               p:vi timer.c            *72%  72%
o:cc -o timer timer.c      p:cc -o timer timer.c   *73%  73%
o:timer                    p:timer                 *74%  74%
o:vi timer.c               p:vi timer.c            *75%  75%
o:cc -o timer timer.c      p:cc -o timer timer.c   *75%  75%
o:timer                    p:timer                 *76%  76%
o:vi timer.c               p:vi timer.c            *77%  77%
o:cc -o timer timer.c      p:cc -o timer timer.c   *77%  77%
o:timer                    p:timer                 *78%  78%
o:vi timer.c               p:vi timer.c            *78%  78%
o:cc -o timer timer.c      p:cc -o timer timer.c   *79%  79%
o:timer                    p:timer                 *80%  80%
o:vi timer.c               p:vi timer.c            *80%  80%
o:cc -o timer timer.c      p:cc -o timer timer.c   *80%  80%
o:timer                    p:timer                 *81%  81%
o:vi timer.c               p:vi timer.c            *81%  81%
o:cc -o timer timer.c      p:cc -o timer timer.c   *82%  82%
o:timer                    p:timer                 *82%  82%
o:vi timer.c               p:vi timer.c            *82%  82%
o:timer                    p:cc -o timer timer.c    81%  82%
o:vi timer.c               p:vi timer.c            *81%  82%
o:timer                    p:cc -o timer timer.c    80%  82%
o:vi timer.c               p:vi timer.c            *80%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *80%  82%
o:timer                    p:timer                 *81%  82%
o:vi timer.c               p:vi timer.c            *81%  82%
o:timer                    p:cc -o timer timer.c    80%  82%
o:mail                     p:vi timer.c             78%  82%
o:remsh rigel              p:                       77%  82%
o:vi timer.c               p:                       75%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *76%  82%
o:timer                    p:timer                 *76%  82%
o:vi timer.c               p:vi timer.c            *77%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *77%  82%
o:vi timer.c               p:timer                  76%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *76%  82%
o:more $inc/setjmp.h       p:timer                  75%  82%
o:vi timer.c               p:                       74%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *74%  82%
o:vi timer.c               p:timer                  73%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *73%  82%
o:vi timer.c               p:timer                  72%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *73%  82%
o:timer                    p:timer                 *73%  82%
o:vi timer.c               p:vi timer.c            *73%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *74%  82%
o:timer                    p:timer                 *74%  82%
o:vi timer.c               p:vi timer.c            *75%  82%
o:cc -o timer timer.c      p:cc -o timer timer.c   *75%  82%
o:timer                    p:timer                 *75%  82%
```

The Return Types of Virtual Functions



WG21+X3J16, the joint ISO ANSI C++ technical committee, is now in its fifth year of work on a standard definition for the C++ programming language and its accompanying library. Over the years, the committee has added more than a dozen new features to the language. I described several of them:

- templates
- exception handling
- new keywords and digraphs to support European translation environments
- `wchar_t` as a keyword
- function and operator overloading for enumeration types
- `operator new[]` and `operator delete[]` for array allocation

in "Recent Language Extensions to C++", *CUJ*, June 1993, and described one other:

- forward declaration of nested classes

in "Nested Classes", *CUJ*, July 1993. This month, I'll explain another extension:

- relaxed restrictions on the return types for virtual functions

This feature enhances the language's support for object-oriented programming. In particular, it extends the set of valid conversions within a type hierarchy that you can write without casting. I assume you are familiar with virtual function in C++, which I described in my last three columns (see "Virtual Functions," "How Virtual Functions Work," and "Overloading and Overriding" in *CUJ*, December, 1993 through February, 1994).

What the ARM Says

According to the *The Annotated C++ Reference Manual* (ARM) (Ellis and Stroustrup [1990]), a member function declared in a derived class `D` overrides a virtual function in its base class `B` only if that function in `D` has the same name and signature (sequence of parameter types) as the function it overrides. Clearly, if the name of a function, say `f`, declared in `D` differs from the name of every function declared in `B`, then `f` doesn't override anything. `f`'s declaration adds a new name to the scope of `D`. If `D` declares a function with the same name, again say `f`, as one or more functions inherited from `B`, but `D`'s `f` has a signature that differs from the signatures of every `f` function in `B`, then again `D`'s `f` doesn't override anything. In this case, `D`'s `f` hides all of `B`'s `f` functions while in the scope of `D`. This is not an error, but as I explained last month, the resulting behavior might surprise you. Consequently, many C++ compilers issue a warning when this sort of hiding occurs.

What about differing return types? According to Section 10.2 of the ARM: "It is an error for a derived class function to differ from a base class virtual function in the return type only." For example, in

```
class B
    {
public:
    virtual int vf(int);
    ...
    };

class D : public B
    {
    ...
    void vf(int); // error
    ...
    };
```

Dan Saks is the president of Saks & Associates, which offers consulting and training in C++ and C. He is secretary of the ANSI and ISO C++ committees. Dan is coauthor of C++ Programming Guidelines, *and codeveloper of the* Plum Hall Validation Suite for C++ *(both with Thomas Plum). You can reach him at 393 Leander Dr., Springfield OH, 45504-4906, by phone at (513)324-3601, or electronically at* dsaks@wittenberg.edu.

the declaration of *D::vf* is an error because it has the same name and signature as a function declared in *B*, but *B::vF* and *D::vF* have different return types.

Consider the consequences of allowing different return types in this situation. A function *g* that accepts a formal parameter of type *B ** or *B &* can apply *vf* to that *B* object, as in

```
void g(B *bp)
    {
    ....
    if (bp->vf(0) > 1)
        ...
    }
```

When compiling this function, the compiler considers only the definition for class *B*. None of the classes derived from *B* need to be declared when compiling *g*. Based on the static type of *B::vf*, the call *bp->vf(0)* in *g* should be just fine; it returns an *int*, as the *if* statement in *g* apparently expects.

Since *D* is publicly derived from *B*, you can pass a *D ** to *g*, as in

```
D d;
...
g(&d);
```

But now if *D::vf* has a void return, how can the call *bp->vf(0)* possibly return an *int*? It can't, which is why the ARM insists that an overriding virtual function must have the same return type as the function it overrides.

Cloning Objects

Some members of the standards committee suggested that this rule is more restrictive than it needs to be. There are, in fact, legitimate circumstances where the return types of the overridden and overriding functions need not be absolutely identical. Clone functions are one such circumstance.

Some applications need to be able to clone an object, that is, create an object that's an exact copy of another object. Typically, you implement a class *X* with a cloning function as something like

```
class X
    {
public:
    X *clone() const
        { return new X(*this); }
    ...
    };
```

Inside *X::clone*, **this* is an expression of type *X* that designates the object being cloned. The expression *new X(*this)* allocates a new *X* object and initializes it using *X*'s copy constructor (the *X* constructor that takes an argument of type *X*). *clone* is a *const* member function because it does not alter **this*, and should thus apply to const as well as non-const objects.

Listing 1 *A class hierarchy with virtual cloning functions that have identical return type*

```
//
// base class 'shape'
//
class shape
    {
public:
    enum palette { BLUE, GREEN, RED };
    shape(palette c);
    virtual double area() const = 0;
    virtual shape *clone() const = 0;
    palette color() const;
    virtual const char *name() const = 0;
    virtual ostream &put(ostream &os) const;
private:
    palette _color;
    static const char *color_image[RED - BLUE + 1];
    };
...

//
// class 'circle' derived from 'shape'
//
class circle : public shape
    {
public:
    circle(palette c, double r);
    double area() const;
    shape *clone() const;
    const char *name() const;
    ostream &put(ostream &os) const;
```

new X returns an *X **. Although you could write a clone function that returns an *X* or an *X &*, I suggest returning *X ** to emphasize that *clone* returns a dynamically-allocated object that should be deleted eventually. In general, for any class *X*, the return type of *X::clone* should be *X **. For example, in a library of geometric shapes, *circle::clone* should return a *circle ** and *rectangle::clone* should return a *rectangle **.

When used in a class that's the root of a polymorphic hierarchy, clone functions should be *virtual*, and often *pure virtual*. This lets you clone an object without knowing its exact type. For example, Listing 1 shows a polymorphic hierarchy of shapes similar to the one I presented three months ago (see "Virtual Functions", *CUJ*, December 1993). Classes *circle*, *rectangle*, and *triangle* are all derived from base class *shape*. *shape* declares a *pure virtual* clone function as:

```
virtual shape *clone() const = 0;
```

Each of the derived classes overrides the clone function with an impure definition. For instance, class *circle* declares

```
virtual shape *clone() const;
```

in the class definition, and later defines

```
shape *circle::clone() const
    {
    return new circle(*this);
    }
```

Not long ago I said that, in general, a clone function for a class *X* should have a return type of *X **. But here the return type of *circle::clone* is *shape **, not *circle **. According to ARM, *circle::clone* must return a *shape ** because that is the return type of the function it overrides. Nonetheless, this clone function is still quite useful.

circle::clone returns the result of *new circle*, which is indeed a *circle **. Since *circle* is publicly derived from *shape*, a *circle* is a *shape*, so the *circle ** in the return expression converts safely and quietly to the return type *shape **. A similar conversion occurs in the clone functions for *rectangle* and *triangle* shown in Listing 1. An application can clone an arbitrary shape with code such as:

```
shape *s;
...
shape *cs = s->clone();
```

which leaves *cs* pointing to an object that has the same dynamic type and value as **s*.

Listing 2 shows a more elaborate example dealing with collections of shapes implemented as arrays of pointers. The *clone_all* function replicates an entire collection of shapes. First, it allocates a new array to hold the pointers to the shape clones. Then, for each shape in the original collection, it clones that shape (using its virtual clone function) and places the pointer to the copy into the new array. As is always the case with polymorphic objects, it doesn't matter to *clone_all* how many different shapes there are; each shape knows how to clone itself.

Unnecessary Downcasting?

The ARM's requirement that the return type of an overriding function must be the same as the return type of the function it

overrides apparently doesn't pose any problems when dealing with pointers (or references) to objects at the root of the hierarchy, as in Listing 2. However, it often necessitates using casts when dealing with pointers to objects of other types in the hierarchy. For example, you cannot write

```
rectangle *r;
...
rectangle *cr = r->clone();
```

Listing 1 *continued*

```
private:
    double radius;
    };

shape *circle::clone() const
    {
    return new circle(*this);
    }

...

//
// class 'rectangle' derived from 'shape'
//
class rectangle : public shape
    {
public:
    rectangle(palette c, double h, double w);
    double area() const;
    shape *clone() const;
    const char *name() const;
    ostream &put(ostream &os) const;
private:
    double height, width;
    };

shape *rectangle::clone() const
    {
    return new rectangle(*this);
    }

...

//
// class 'triangle' derived from 'shape'
//
class triangle : public shape
    {
public:
    triangle(palette c, double s1, double s2, double a);
    double area() const;
    shape *clone() const;
    const char *name() const;
    ostream &put(ostream &os) const;
private:
    double side1, side2, angle;
    };

shape *triangle::clone() const
    {
    return new triangle(*this);
    }

...

// End of File
```

because *r->clone()* returns a *shape **. Even though a *rectangle* is a *shape*, a *shape* is not necessarily a *rectangle*. Therefore, you must add a cast, as in

```
rectangle *cr = (rectangle *)r->clone();
```

Casts are dangerous things. They tell the compiler to stop complaining and let you do what you want to do, or at least, what you think you want to do. But compilers are right more often than we care to admit. Casts indicate that you are doing something that is generally unsafe. Thus, you really should avoid casts in your C++ programs, probably even more so than in C programs. When casts are rare, the few casts you really do need will stand out and draw more scrutiny, which they deserve. (For more about avoiding casts, see Plum and Saks [1991].)

Of course, you don't really need a cast in the previous example, because you don't really need to call *clone* to replicate a *shape* that you know is a *rectangle*. Rather, you can simply *clone* **r* with

```
rectangle *cr = new rectangle(*r);
```

But consider what happens if *rectangle* and *triangle* (and any other polygons) are derived from an abstract base class *polygon* derived from *shape*, rather than directly from *shape*, as outlined in Listing 3. (An abstract base class is a class with at least one *pure virtual* function. An abstract base class can be a derived class.)

To satisfy the ARM, all the clone functions in Listing 3 return a *shape **. (The declaration of *polygon's* clone function is inside a comment because you don't really need it. A function declared *pure virtual* in a base class remains *pure virtual* in the derived class unless overridden with an impure declaration.) When you clone a *polygon*, you get a pointer of type *shape **, even though you know that pointer specifically addresses a *polygon*. Thus, you cannot clone a *polygon* and copy the result to a *polygon ** without a cast. That is, you cannot omit the cast in

Listing 2 *A crude application of the shape hierarchy in Listing 1*

```
//
// 'clone_all' clones shape array 'sa1' with 'n'
// elements
//
shape **clone_all(shape *sa1[], size_t n)
    {
    shape **sa2 = new shape *[n];
    for (size_t i = 0; i < n; ++i)
        sa2[i] = sa1[i]->clone();
    return sa2;
    }

//
// 'largest' returns the shape with the largest
// area from shape array 'sa' with 'n' elements
//
shape *largest(shape *sa[], size_t n)
    {
    shape *s = 0;
    double m = 0;
    for (size_t i = 0; i < n; ++i)
        if (sa[i]->area() > m)
            {
            m = sa[i]->area();
            s = sa[i];
            }
    return s;
    }

int main()
    {
    const int N = 4;
    shape *s[N];
    shape *ls;
    s[0] = new circle(shape::RED, 2);
    s[1] = new triangle(shape::BLUE, 5, 6, asin(0.8));
    s[2] = new rectangle(shape::RED, 3, 4);
    s[3] = new circle(shape::GREEN, 3);
    cout << "The shapes are:\n";
    for (int i = 0; i < N; ++i)
        cout << i << ")\t" << *s[i] << '\n';
    cout << '\n';
    shape **cs = clone_all(s, N);
    cout << "The cloned shapes are:\n";
    for (i = 0; i < N; ++i)
        cout << i << ")\t" << *cs[i] << '\n';
    cout << '\n';
    ls = largest(cs, N);
    cout << "The shape with the largest area is a...\n\t";
    cout << *ls << ".\n";
    cout << "Its area is " << ls->area() << ".\n";
    return 0;
    }

// End of File
```

All of the casts in the previous examples cast pointers to base class objects into pointers to derived class objects. These casts are commonly called "downcasts" because most people draw class hierarchies with the base classes above their derived classes. Remember, when a class *D* is publicly derived from *B*, a *D* is a *B*, so you can safely convert a `D *` to a `B *` without a cast. But a `B *` is not necessarily a `D *`, so you can't convert a `B *` downward to a `D *` without a cast. Thus, like all other casts, downcasts are generally unsafe unless you're absolutely, positively sure that your `B *` actually points to a *D*.

But the downcast in

```
polygon *cp = (polygon *)p->clone();
```

is actually quite safe because we do know that *p->clone()* returns a *polygon **. In fact, there's a whole family of similarly safe downcasts that occur commonly in object-oriented systems. The problem is that, on the surface, the safe casts look just like the unsafe ones. The cure is to augment the rules for virtual overriding so that you can write the safe conversions without casts.

For example, you should be able to declare each virtual clone function in a hierarchy so that it returns a pointer whose static type is the same as its dynamic type. That is, *circle::clone* a cast. For instance, given

Listing 3 *The* `shape` *hierarchy with* `rectangle` *and* `triangle` *derived from abstract base class* `polygon`

```
class shape
    {
public:
    ...
    virtual shape *clone() const = 0;
    ...
    };

...

class circle : public shape
    {
public:
    shape *clone() const;
    ...
    };

shape *circle::clone() const
    {
    return new circle(*this);
    }

...

class polygon : public shape
    {
public:
//  shape *clone() const = 0;   // still pure
    ...
    };

...

class rectangle : public polygon
    {
public:
    shape *clone() const;
    ...
    };

shape *rectangle::clone() const
    {
    return new rectangle(*this);
    }

...

class triangle : public polygon
    {
public:
    shape *clone() const;
    ...
    };

shape *triangle::clone() const
    {
    return new triangle(*this);
    }

...

// End of File
```

```
shape *s;
circle *c;
```

you can write

```
shape *cs = s->clone();
```

to clone a *shape*, and

```
circle *cc = c->clone();
```

to clone a *circle*.

In a sense, declaring *circle::clone* to return a *circle ** doesn't introduce any new conversions. It merely shifts the exact point where the conversions occur, or eliminates the conversions altogether. For example, when you write *circle::clone* as

```
shape *circle::clone() const
    {
    return new circle(*this);
    }
```

a conversion from *circle ** to *shape ** occurs as part of the return statement. Then there's no conversion at all in a calling expression like

```
shape *s;
...
shape *cs = s->clone();
```

In contrast, when you write *circle::clone* as

```
circle *circle::clone() const
    {
    return new circle(*this);
    }
```

no conversion occurs inside the function, but an implicit conversion from *circle ** (or *rectangle ** or *triangle **) to *shape ** occurs in the calling expression. The net effect is the same.

The New, Relaxed Rules

The C++ standards committee agreed that the ARM's requirement on the return type of virtual functions is a bit too restrictive. Thus, the current draft of the Working Paper (the standard-to-be) relaxes the original rule. The new rule as it appears in the Working Paper is jargon-rich and seems to change with each new draft, so I'll spare you the exact words. Here's more-or-less what it says:

For all classes *B* and *D* defined as

```
class B
    {
    virtual BT f();
    ...
    };

class D : public B
    {
    ...
```

```
    DT f();
    ...
    };
```

types *BT* and *DT* must be identical, or they must satisfy either of the following conditions:

1. *BT* is `BB *` and *DT* is `DD *` where *DD* is derived from *BB*.
2. *BT* is `BB &` and *DT* is `DD &` where *DD* is derived from *BB*.

In either case (1) or (2),

3. class *D* must have the access rights to convert a `BB *` (or `BB &`) to a `DD *` (or `DD &`, respectively).

In most common applications, *BB* is a public base class of *DD*, so *D* can perform the conversions. But, for example, if *BB* is a private base class of *DD* then the conversions are not valid, and *BT* and *DT* will not satisfy condition (3).

The above rules apply even if *D* is derived indirectly from *B*. Or, *BB* might be *B* and *DD* might be *D*. The latter, in fact, is the case with clone functions.

Listing 4 shows the shape hierarchy of Listing 1 rewritten using the new relaxed rules for the return type of virtual functions. For completeness, I've included all the member function bodies so you can use them to build and execute the test code in Listing 2.

Although the committee adopted these relaxed rules in March, 1992, I believe most vendors have yet to release a C++ compiler that supports them. As of early 1994, only two of the six PC-based compilers I own (Borland 4.0 and Watcom 9.5) can compile Listing 4 without error.

cv-qualifiers in Return Types

According to the current (September 1993) Working Paper, the cv-qualifiers (*const* and *volatile*) in the return types of the overriding and overridden functions need not be identical. My understanding is that the overriding function's return type cannot have

Listing 4 *The shape class hierarchy with virtual cloning functions employing the relaxed return type rules*

```
#include <iostream.h>
#include <math.h>
#include <stddef.h>

//
// base class 'shape'
//
class shape
    {
public:
    enum palette { BLUE, GREEN, RED };
    shape(palette c);
    virtual double area() const = 0;
    virtual shape *clone() const = 0;
    palette color() const;
    virtual const char *name() const = 0;
    virtual ostream &put(ostream &os) const;
private:
    palette _color;
    static const char *color_image[RED - BLUE + 1];
    };

const char *shape::color_image[shape::RED - shape::BLUE + 1] =
    { "blue", "green", "red" };

shape::shape(palette c) : _color(c) { }

ostream &shape::put(ostream &os) const
    {
    return os << color_image[color()] << ' ' << name();
    }

shape::palette shape::color() const
    {
    return _color;
    }

//
// class 'circle' derived from 'shape'
//
const double pi = 3.1415926;

class circle : public shape
    {
public:
    circle(palette c, double r);
    double area() const;
    circle *clone() const;
    const char *name() const;
    ostream &put(ostream &os) const;
private:
    double radius;
    };

circle::circle(palette c, double r) : shape(c), radius(r) { }

double circle::area() const
    {
    return pi * radius * radius;
    }
```

Listing 4 *continued*

```
const char *circle::name() const
    {
    return "circle";
    }

ostream &circle::put(ostream &os) const
    {
    return shape::put(os) << " with radius = " << radius;
    }

circle *circle::clone() const
    {
    return new circle(*this);
    }

//
// class 'rectangle' derived from 'shape'
//
class rectangle : public shape
    {
public:
    rectangle(palette c, double h, double w);
    double area() const;
    rectangle *clone() const;
    const char *name() const;
    ostream &put(ostream &os) const;
private:
    double height, width;
    };

rectangle::rectangle(palette c, double h, double w)
    : shape(c), height(h), width(w) { }

double rectangle::area() const
    {
    return height * width;
    }

const char *rectangle::name() const
    {
    return "rectangle";
    }

ostream &rectangle::put(ostream &os) const
    {
    return shape::put(os) << " with height = " << height
        << " and width = " << width;
    }

rectangle *rectangle::clone() const
    {
    return new rectangle(*this);
    }

//
// class 'triangle' derived from 'shape'
//
class triangle : public shape
    {
public:
    triangle(palette c, double s1, double s2, double a);
    double area() const;
    triangle *clone() const;
    const char *name() const;
    ostream &put(ostream &os) const;
private:
    double side1, side2, angle;
    };

triangle::triangle(palette c, double s1, double s2, double a)
    : shape(c), side1(s1), side2(s2), angle(a) { }

double triangle::area() const
    {
    return side1 * sin(angle) * side2 / 2;
    };

const char *triangle::name() const
    {
    return "triangle";
    }

ostream &triangle::put(ostream &os) const
    {
    return shape::put(os) << " with one side = " << side1
        << ", another side = " << side2
        << " and angle = " << angle;
    }

triangle *triangle::clone() const
    {
    return new triangle(*this);
    }

ostream &operator<<(ostream &os, const shape &s)
    {
    return s.put(os);
    }

// End of File
```

any cv-qualifiers that are not also in the overridden function's return type. Listing 5 shows some examples.

Class *B* in Listing 5 declares virtual function *f* with a return type *const BB **, but class *D* overrides it with a function that returns *DD ** (where *DD* is publicly derived from *BB*). Hence, if *bp* is a *B ** that actually points to a *D*, then

```
const BB *bbp = bp->f();
```

invokes *D::f* applied to **b*. *D::f* returns a pointer to a non-const *DD* object, which the expression *bp->f()* quietly converts to *const BB **.

Pointer conversions that add cv-qualifiers are always safe, but conversions that strip off cv-qualifers are not. Thus, given

```
char *cp;
const char *ccp;
```

then

```
ccp = cp;
```

is safe, but

```
cp = ccp;
```

is not. Similarly, as you convert derived types to their base types, adding cv-qualifiers to pointer types should not make the conversions any less safe.

Listing 5 also shows that derived class *D* has a virtual function *g* returning a *const DD &* that overrides a function returning a *const volatile BB &*. This is also valid. However, if you omit *volatile* from the return type of *B::g*, then *D::f* is erroneous.

None of the compilers I own support this feature yet.

More to Come

Over the past two years, the standards committee has added several other new features to C++:

- run-time type identification
- mutable members for *const* objects
- namespaces
- a predefined boolean type
- new syntax for casts

I will explain them all in upcoming columns.

Meeting Dates, Etc.

WG21+X3J16 will meet three times in 1994:

- March 6-11 in San Diego, CA USA
- July 10-15 in Waterloo, Ontario Canada
- November 6-11 in Valley Forge, PA USA

If all goes as scheduled, the draft standard should be available for public review and comment shortly after the July meeting.

If you would like to participate in the standards process as a member of X3J16, contact the vice-chair:

Josée Lajoie
IBM Canada Laboratory
844 Don Mills Rd.
North York, Ontario M3C 1V7 Canada
(416)448-2734
josee@vnet.ibm.com□

References

Ellis and Stroustrup [1990]. Margaret A. Ellis and Bjarne Stroustrup. *The Annotated C++ Reference Manual.* Addison- Wesley.

Plum and Saks [1991]. Thomas Plum and Dan Saks. *C++ Programming Guidelines.* Plum Hall.

Listing 5 *A derived class whose virtual functions have fewer cv-qualifiers than the functions they override*

```
class B
    {
    ...
    virtual const BB *f();
    virtual const volatile BB &g();
    ...
    };

class D : public B
    {
    ...
    DD *f();
    const DD &g();
    ...
    };

// End of File
```

Chuck Allison

The Preprocessor

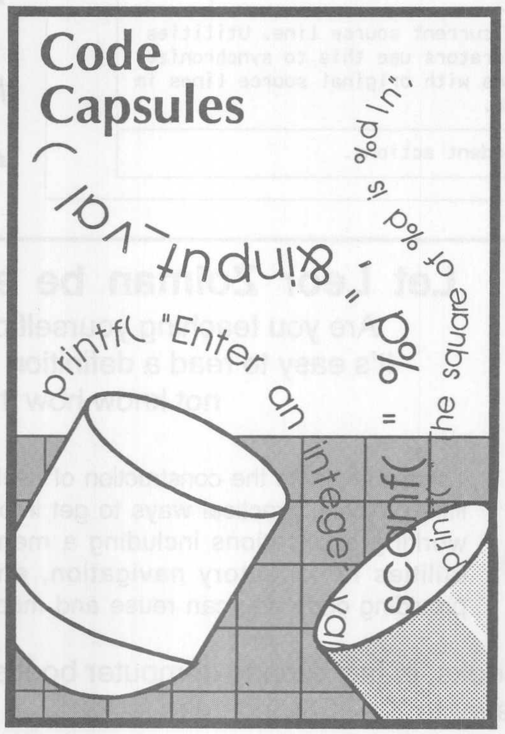
To use C effectively you really have to master two languages: the C language proper and the preprocessor. Before a compiler begins the usual chores of syntax checking and instruction translation, it submits your program to a preliminary phase called preprocessing, which alters the very *text* of the program according to your instructions. The altered text that the compiler sees is called a *translation unit*. In particular, the preprocessor performs the following three functions for you:

1) header/source file inclusion

2) macro expansion

3) conditional compilation

In this article I will illustrate these features of the preprocessor.



The Include Directive

One of the first source lines any C programmer sees or composes is this:

```
#include <stdio.h>
```

Take a moment right now and jot down everything you know about this statement.

Let's see how you did. `stdio.h` is of course a standard library header, so called because such include directives usually appear near the beginning of a source file so that their definitions will be in force throughout the rest of the compilation. We commonly think of it as a header *file*, but there is no requirement that the definitions and declarations pertaining to standard input and output reside in a file. The C Standard only requires that these definitions and declarations replace the include directive in the text of the program before translation. They could reside in tables internal to the preprocessor. Most compiler implementations do supply header files for the standard library, however. MS-DOS compilers install header files in a suitable subdirectory. Here is a sampling:

```
\BC4\INCLUDE          /* Borland C++ 4.0 */
\MSVC\INCLUDE         /* Microsoft Visual C++ */
\WATCOM\H             /* Watcom C/C++ */
```

On UNIX systems you will find header files in `/usr/include`.

Since an implementation is not even obliged to supply headers in the form of physical files, it's no surprise that those implementations providing files don't always give them the same name as the include directive. After all, how could a compiler supply a file named `stdio.h` on a platform whose file system didn't allow periods in a file name? On MS-DOS systems there can be no file that exactly matches the C++ header `<strstream.h>`, because the file system only allows up to eight characters before the period.

Most MS-DOS implementations map header names into file names by truncating the base part (the portion before the period) to eight characters, and the extension to three (so the definitions for `<strstream.h>` reside in the file `STRSTREA.H`). A standard-conforming implementation must supply a mapping to the local file system for user-defined header names having at least six characters before the period and one character after.

Conforming compilers also support include directives with string-like arguments, as in:

```
#include "mydefs.h"
```

The string must represent a name recognized by the local file system. The file must be a valid C/C++ source file and, like the standard headers, usually contains function prototypes, macro definitions, and other declarations. An implementation must specify the mechanism it uses to locate the requested source file. On platforms with hierarchical file systems, the compiler usually searches the current directory first. If that fails, it then searches the subdirectory

Chuck Allison is a regular columnist with CUJ *and a software architect for the Family History Department of the Church of Jesus Christ of Latter Day Saints Church Headquarters in Salt Lake City. He has a B.S. and M.S. in mathematics, has been programming since 1975, and has been teaching and developing in C since 1984. His current interest is object-oriented technology and education. He is a member of X3J16, the ANSI C++ Standards Committee. Chuck can be reached on the Internet at* `allison@decus.org`, *or at (801)240-4510.*

reserved for the standard headers. Because standard header names are special preprocessing tokens and not strings, any backslashes in a header name are not interpreted as escape characters. In the following directive, a double backslash is not needed.

```
#include <sys\stat.h>               /* \, not \\ */
#include "\project\include\mydefs.h"
```

Included files may themselves contain other include directives, nested up to eight levels deep. Since some definitions (like typedefs) must only appear once during a compilation, you must guard against the possibility of a file being included more than once. The customary technique defines a symbol associated with the file. Exclude the text of the file from the compilation if the symbol has already been seen by the compiler, as in the following:

```
/* mydefs.h */
#ifndef MYDEFS_H
#define MYDEFS_H

<declarations/definitions go here>

#endif
```

Macros

As you can see, there's more to the *#include* directive than meets the eye. C

Table 1 *Preprocessor directives*

`#include`	Includes text of header or source file.
`#define`	Enters a symbol into the symbol table for the current compilation unit, with an optional value.
`#undef`	Removes a symbol from the symbol table.
`#if` `#elif` `#else` `#endif`	Control flow directives for conditional compilation.
`#ifdef` `#ifndef`	Symbol table query directives. (Also used for conditional compilation).
`#line`	Renumbers the current source line. Utilities like code generators use this to synchronize generated lines with original source lines in error messages.
`#pragma`	Compiler-dependent actions.

provides eleven other preprocessor directives you can use to alter your source text in meaningful ways (see Table 1). (All begin with the '#' character, which must be the first non-space character on its source line.) In this section I elaborate on one of the other directives, the *#define* directive, to introduce a very useful construct called a *macro*.

The *#define* directive creates macro definitions. A macro is a name for a sequence of zero or more preprocessing tokens. (Valid preprocessing tokens include valid C language tokens such as identifiers, strings, numbers and operators; and any single character). For example, the line

```
#define MAXLINES 500
```

associates the text *500* with the symbol *MAXLINES*. The preprocessor keeps a table of all symbols created by the *#define* directive, along with the corresponding replacement text. Whenever the preprocessor encounters the token *MAXLINES* outside of a quoted string or comment, it replaces *MAXLINES* with the token *500*. In later phases of compilation it appears as if you actually typed *500* instead of *MAXLINES*. It is important to remember that this operation consists of mere *text replacement*. No semantic analysis occurs during preprocessing.

A macro without parameters, such as *MAXLINES*, is sometimes called an *object-like* macro because it defines a program constant that looks like an object. Because object-like macros are often constants, it is customary to type them in upper case as a hint to the reader. You can also define *function-like* macros with zero or more parameters, as in the following code fragment:

```
#define beep()    putc('\a',stderr)
#define abs(x)    ((x) >= 0 ? (x) : (-(x)))
#define max(x,y)  (((x) > (y)) ? (x) : (y))
```

There must be no whitespace between the macro name and the first left parenthesis. The expression

```
abs(-4)
```

expands to

```
((-4) >= 0 ? (4) : (-(4)))
```

You should always parenthesize macro parameters (such as *x*) in the replacement text. This practice prevents surprises from unexpected precedence in complex expressions. For example, if you had used the following naive mathematical definition for absolute value:

```
x >= 0 ? x : -x
```

then the expression *abs(a - 1)* would expand to

```
a - 1 >= 0 ? a - 1 : -a - 1
```

which is incorrect when *a - 1 < 0* (it should be *-(a - 1)*).

Even if you put parentheses around all arguments, you should usually parenthesize the entire replacement expression as well to avoid surprises with respect to the surrounding text. To see this, define *abs()* without enclosing parens, as in:

```
#define abs(x) (x) >= 0 ? (x) : (-x)
```

Then *abs(a) - 1* expands to

```
(a) >= 0 ? (a) : -(a) - 1
```

Table 2 *Pre-defined macros*

Macro	Value
`__LINE__`	The number of the current source line (equal to one more than the number of newline characters read so far).
`__FILE__`	The name of the source file.
`__DATE__`	The date of translation, in the form "Mmm dd yyyy."
`__TIME__`	The time of translation, in the form "hh:mm:ss".
`__STDC__`	1, if the compilation is in "standard" mode.

It is also dangerous to use expressions with side effects as macro arguments. For example, the macro call *abs(i++)* expands to

```
((-i++) >= 0 ? (i++) : (-(i++)))
```

Listing 1 *Prints the pre-defined macros*

```
/* sysmac.c:    Print system macros */

#include <stdio.h>

main()
{
    printf("__DATE__ == %s\n",__DATE__);
    printf("__FILE__ == %s\n",__FILE__);
    printf("__LINE__ == %d\n",__LINE__);
    printf("__TIME__ == %s\n",__TIME__);
    printf("__STDC__ == %d\n",__STDC__);
    return 0;
}

/* Output:
__DATE__ == Dec 18 1993
__FILE__ == sysmac.c
__LINE__ == 9
__TIME__ == 19:05:06
__STDC__ == 1
*/
/* End of File */
```

probably isn't what you had in mind.

Pre-defined Macros

Conforming implementations supply the five built-in object-like macros shown in Table 2. The last three macros remain constant during the compilation of a leading underscore followed by either an uppercase letter or another underscore.

Listing 2 *Illustrates an assertion failure*

```
/* fail.c */
#include <stdio.h>
#include <assert.h>

main()
{
    int i = 0;

    assert(i > 0);
    return 0;
}

/* Sample Execution:
C:>assert
Assertion failed: i > 0,
    file assert.c, line 9
Abnormal program termination
*/
/* End of File */
```

You may not redefine any of these five macros with the *#define* directive, nor remove them with the *#undef* directive. Most compilers support multiple modes, some of which are not standard-conforming. (To guarantee that the sample program in Listing 1 will run correctly under Borland C, for example, you need to run in "ANSI mode" via the "-A" command-line option.)

Conforming compilers also provide a function-like macro, *assert*, which you can use to put diagnostics in programs. If its argument evaluates to zero, *assert* prints the argument along with source file name and line number (using *__FILE__* and *__LINE__*) to the standard error device and aborts the program (see Listing 2). For more information on using the *assert* macro, see the Code Capsule "File Processing, Part 2" in the June 1993 issue of *CUJ*.

A compiler is allowed to provide macro versions for any functions in the standard library (*getc* and *putc* usually come as macros for efficiency). With the exception of a handful of required function-like macros (*assert*, *setjmp*, *va_arg*, *va_end*, and *va_start*), an implementation must also supply true function versions for all functions in the standard library. A macro version of a library function in effect hides its prototype from the compiler, so its arguments are not type-checked during translation. To force the true function to be called, remove the macro definition with the *#undef* directive, as in

```
#undef getc
```

Alternatively, you can surround the function name in parentheses when you call it, as in:

```
c = (getc)(stdin);
```

There's no danger of this expression matching the macro definition since a left parenthesis does not immediately follow the function name.

Conditional Compilation

You can selectively include or exclude segments of code with conditional directives. For example, you can embed the following excerpt in your code to accommodate different syntaxes of the *delete* operator in earlier versions of C++:

```
#if VERSION < 3
    delete [strlen(p) + 1] p;
#else
    delete [] p;
#endif
```

Your compiler probably supplies a macro similar to *VERSION* (Borland C++ defines *__BCPLUSPLUS__*, Microsoft *_MSCVER*). The argument of an *#if* directive must evaluate to an integer constant, and obeys the usual C rule of non-zero means true, zero false. You cannot use casts or the *sizeof* operator in such expressions.

C++ implementations also pre-define the macro __cplusplus, which you can use to customize your code for mixed C/C++ environments. For example, if you want to link with existing C code in a C++ environment, you need to use the extern "C" linkage specification (which of course is not valid in a C environment). The following excerpt will do the right thing in either environment:

```
#ifdef __cplusplus
extern "C"
{
#endif

<put C declarations here>

#ifdef __cplusplus
#endif
```

The *#if* directive is handy when you want to comment out long passages of code. You can't just wrap such sections in a single, enclosing comment because there are likely to be comments in the code itself (right?), causing the outer comment to end prematurely. It is better to enclose the code in question in the body of an *#if* directive that always evaluates to zero:

```
#if 0
<put code to be ignored here>
#endif
```

Preprocessor Operators

Sometimes you just want to know if a macro is defined, without using its value. For example, if you only support two compilers, you might have something like the following in your code:

```
#if defined _MSCVER
<put Microsoft-specific statements here>
#elif defined __BCPLUSPLUS__
<put Borland-specific statements here>
#else
#error Compiler not supported.
#endif
```

defined is one of three preprocessor operators (see Table 3). The *defined* operator evaluates to 1 if its argument is present in the symbol table, meaning that the macro was either defined by a previous *#define* directive or the compiler provided it as a built-in macro. The *#error* directive prints its argument as a diagnostic and halts the translator.

It isn't necessary to assign a value to a macro. For example, to insert debug trace code into your program, you can do the following:

```
#if defined DEBUG
fprintf(stderr,"x = %d\n",x);
#endif
```

To define the DEBUG macro, just insert the following statement before the first use of the macro:

```
#define DEBUG
```

The following equivalences are recognized by the preprocessor:

```
#if defined X       <==>        #ifdef X
#if !defined X      <==>        #ifndef X
```

Using the *defined* operator is more flexible than the equivalent directives on the right because you can combine multiple tests as a single expression, as in:

```
#if defined __cplusplus && !defined DEBUG
```

The operator #, the "stringizing" operator, effectively encloses a macro argument in quotes. As the program in Listing 3 illustrates, stringizing can be useful for debugging. The *trace()* macro encloses its arguments in quotes so they become part of a *printf* format statement. For example, the expression *trace(i,d)* becomes

```
printf("i" " = %" "d" "\n",i);
```

and, after the compiler concatenates adjacent string literals it sees this:

```
printf("i = %d\n",i);
```

There is no way to build quoted strings like this without the stringizing operator because the preprocessor ignores macros inside quoted strings.

The token-pasting operator, ##, concatenates two tokens together to form a single token. The call *trace2(1)* in Listing 4 is translated into

```
trace(x1,d)
```

Any space surrounding these two operators is ignored.

Implementing *assert()*

Implementing *assert* reveals an important fact about using macros. Since the action of *assert* depends on the result of a test, you might first try an *if* statement, as in:

```
#define assert(cond) \
  if (!(cond)) __assert(#cond,__FILE__,__LINE__)
```

where the function *__assert* prints the message and halts the program. This implementation causes a problem, however, when *assert* finds itself within an *if* statement, as in:

```
if (x > 0)
    assert(x != y)
else
    /* whatever */
```

because the preceding code expands into

```
if (x > 0)
    if (!(x != y)) __assert("x != y","file.c",7);
else
    /* whatever */
```

The indentation that results from expanding *assert* in place is misleading because it's actually the second *if* that intercepts the *else*. Rewriting the expanded code to represent the actual flow of control produces:

```
if (x > 0)
    if (!(x != y))
        __assert("x != y","file.c",7)
    else /* OOPS! New control flow! */
        /* whatever */
```

The usual fix for nested if problems such as this is to use braces, as in:

```
#define assert(cond) \
{if (!(cond)) __assert
    (#cond,__FILE__,__LINE__)   }
```

Listing 3 *Illustrates the stringizing operator*

```
/* trace.c: Illustrate a trace  *
 * macro for debugging          */

#include <stdio.h>

#define trace(x,format) \
    printf(#x " = %" #format "\n",x)

main()
{
    int i = 1;
    float x = 2.0;
    char *s = "three";

    trace(i,d);
    trace(x,f);
    trace(s,s);
    return 0;
}

/* Output:
i = 1
x = 2.000000
s = three
*/
/* End of File */
```

Listing 4 *Illustrates the token-pasting operator*

```
/* trace2.c: Illustrate a trace  *
 * macro for debugging           */

#include <stdio.h>

#define trace(x,format) \
    printf(#x " = %" #format "\n",x)
#define trace2(i) trace(x ## i,d)

main()
{
    int x1 = 1, x2 = 2, x3 = 3;
    trace2(1);
    trace2(2);
    trace2(3);
    return 0;
}

/* Output:
x1 = 1
x2 = 2
x3 = 3
*/
/* End of File */
```

but this code expands into

```
if (x > 0)
     {if (!(x != y)) __assert
          ("x != y","file.c",7)};
else
     /* whatever */
```

and the combination *}*; in the second line creates a null statement that completes the outer `if`, leaving a dangling `else`, which is a syntax error. A correct way to define `assert` is shown in Listing 5. (This simple version does not recognize the macro `NDEBUG`.) (Listing 6 shows the implementation of the support function `__assert()`). In general, when a macro must make a choice, it is good practice to write it as an expression and not as a statement.

Macro Magic

It's important to understand precisely what steps the preprocessor follows to expand macros, otherwise you can be in for some mysterious surprises. For example, if you insert the following line near the beginning of Listing 4:

```
#define x1 SURPRISE!
```

then `trace2(1)` expands into

```
trace(x ## 1,d)
```

which in turn becomes

```
trace(x1,d)
```

But the preprocessor doesn't stop there. It *rescans* the line to see if any other macros need expanding. The final state of the program text seen by the compiler is shown in Listing 7.

To further illustrate, consider the text in Listing 8. Listing 8 is not a complete program, by the way, but is for preprocessing only — don't try to compile it all the way. (If you have Borland C use the CPP command.) The output from the preprocessor appears in Listing 9. The `str()` macro just puts quotes around its argument. It might appear that `xstr()` is redundant, but there is an important difference between `xstr()` and `str()`. The output of the statement `str(VERSION)` is of course

Table 3 *Preprocessor operators*

Operator	Usage
#	Stringizing
##	Token pasting
defined	Symbol table query

```
"VERSION"
```

but *xstr(VERSION)* expands to

```
str(2)
```

because arguments not connected with a `#` or `##` are *fully expanded* before they replace their respective parameters. The preprocessor then rescans the statement, providing *"2"*. So in effect, `xstr()` is a version of `str()` that expands its argument before quoting it.

The same relationship exists between `glue()` and `xglue()`. The statement `glue(VERSION,3)` concatenates its arguments into the token *VERSION3*, but `xglue(VERSION,3)` first expands *VERSION*, producing

```
glue(2,3)
```

which in turn rescans into the token 23.

The next two statements are a little trickier:

```
glue(VERS,ION)
== VERS ## ION
== VERSION
== 2
```

and

```
xglue(VERS,ION)
== glue(VERS,ATILE)
== VERS ## ATILE
== VERSATILE
```

Of course, if *VERSATILE* were a defined macro it would be further expanded.

The last four statements in listing 8 expand as follows:

```
ID(VERSION)
== "This is version "xstr(2)
== "This is version "str(2)
== "This is version ""2"

INCFILE(VERSION)
== xstr(glue(version,2)) ".h"
== xstr(version2) ".h"
== "version2" ".h"

str(INCFILE(VERSION))
== #INCFILE(VERSION)
== "INCFILE(VERSION)"

xstr(INCFILE(VERSION))
== str("version2" ".h")
== #"version2" ".h"
== "\"version2\" \".h\""
```


Listing 5 *A simple implementation of the* assert *macro*

```
/* assert.h */

extern void __assert(char *, char *, long);

#undef assert
#ifdef NDEBUG
#define assert(cond)
    (void) 0
#else
#define assert(cond) \
    ((cond)         \
    ? (void) 0      \
    : __assert(#cond,__FILE__,__LINE__))
/* End of File */
```

Listing 6 *The* __assert *support function*

```
/* xassert.c */
#include <stdio.h>
#include <stdlib.h>

void __assert(char *cond, char *fname, long lineno)
{
    fprintf(stderr,
        "Assertion failed: %s, file %s, line %ld\n",
        cond,fname,lineno);
    abort();
}

/* End of File */
```

For obvious reasons, the # operator effectively inserts escape characters before all embedded quotes and backslashes.

The macro replacement facilities of the preprocessor clearly offer you an incredible amount of flexibility (too much, some would say). There are two limitations to keep in mind:

1) If at any time the preprocessor encounters the current macro in its own replacement text, no matter how deeply nested in the process, the preprocessor does not expand it but leaves it as-is (otherwise the process would never terminate!). For example, given the definitions

```
#define F(f) f(args)
#define args a,b
```

F(g) expands to *g(a,b)*, but what does *F(F) expand to? (Answer: F(a,b)).*

2) If a fully-expanded statement resembles a preprocessor directive, (e.g., if expansion results in an *#include* directive), the directive is *not* invoked, but is left verbatim in the program text. (Thank goodness!).

Character Sets and Trigraphs

The character set you use to compose your program doesn't have to be the same as the one in which the program executes. These two character sets often differ in non-English applications. A C translator only understands the *source character set* — English alphanumerics, the graphics characters used for operators and punctuators (there are 29 of them), and a few control characters (newline, horizontal tab, vertical tab, and form-feed). Any other characters presented to the translator may appear only in quoted strings, character constants, header names or comments. The *execution character set* is the set of characters that the program uses in its literals, and to input and output data. This set is implementation-defined, but must at least contain characters representing alert (*'\a'*), backspace (*'\b'*), carriage return (*'\r'*), newline (*'\n'*), form feed (*'\f'*), vertical tab (*'\v'*), and horizontal tab (*'\t'*).

Many non-U.S. environments use different graphics for some of the elements of the source character set, making it impossible to write readable C programs. To overcome this obstacle, standard C defines a number of *trigraphs*, which are triplets of characters from the Invariant Code Set (ISO 646-1983) found in virtually every environment in the world. Each trigraph corresponds to a character in the source character set which is not in ISO 646 (see Table 4). For example, whenever the preprocessor encounters the token *??=* anywhere in your source text (even in strings), it replaces this token with the '#' character code from the source character set.

Listing 7 *Preprocessed source with a surprise*

```
main()
{
int SURPRISE! = 1, x2 = 2, x3 = 3;
printf("x1" " = %" "d" "\n",SURPRISE!);
printf("x2" " = %" "d" "\n",x2);
printf("x3" " = %" "d" "\n",x3);
return 0;
}
/* End of File */
```

The program in Listing 11 shows how to write the "Hello, world!" program from Listing 10 using trigraphs. (Borland users: you have a separate executable, *trigraph.exe*, for procesing trigraphs.)

In an effort to enable more readable programs world-wide, the C++ draft standard defines a set of digraphs and new keywords for non-ASCII developers (see Table 5). Listing 12 shows what "Hello, world" looks like using these new tokens. Perhaps you will agree that the symmetric look of the bracketing operators is easier on the eye.

Phases Of Translation

The C standard defines eight distinct phases of translation. An implementation doesn't make eight separate passes through the code, of course, but the result of translation must behave as if it had. The eight phases are:

1. Physical source characters are mapped into the source character set. This includes trigraph replacement and things like mapping a carriage return/line feed to a single newline character in MS-DOS.
2. All lines that end in a backslash are merged with their continuation line, and the backslash is deleted.
3. The source is parsed into preprocessing tokens and comments are replaced with a single space character. The C++ digraphs are recognized as tokens.
4. Preprocessing directives are invoked and macros are expanded. Steps 1 through 4 are repeated for any *include*d files.
5. Escape sequences in character constants and string literals that represent characters in the execution set are converted (e.g., `'\a'` would be converted to a byte value of 7 in an ASCII environment).
6. Adjacent string literals are concatenated.
7. Traditional compilation occurs: lexical and semantic analysis, and translation to assembly or machine code.
8. Linking occurs: external references are resolved and a program image is made ready for execution.

The preprocessor performs steps 1 through 4.

C++ And The Preprocessor

C++ preprocessing formally differs from that of C only in the tokens it recognizes. A C++ preprocessor must recognize the tokens in Table 5 as well as `.*`, `->*`, and `::`. It must also recognize `//`-style comments and replace them with a single space. Though

Listing 8 *Illustrates macro rescanning*

```
/* preproc.c:  Test # and ## preprocessing operators
 *
 *  NOTE:    DO NOT COMPILE! Preprocess only!
 */

/* Handy stringizing macros */
#define str(s) #s
#define xstr(s) str(s)

/* Handy token-pasting macors */
#define glue(a,b) a##b
#define xglue(a,b) glue(a,b)

/* Some definitions */
#define ID(x) "This is version " ## xstr(x)
#define INCFILE(x) xstr(glue(version,x)) ".h"
#define VERSION 2
#define ION ATILE

/* Expand some macros */
str(VERSION)
xstr(VERSION)
glue(VERSION,3)
xglue(VERSION,3)
glue(VERS,ION)
xglue(VERS,ION)

/* Expand some more */
ID(VERSION)
INCFILE(VERSION)
str(INCFILE(VERSION))
xstr(INCFILE(VERSION))
/* End of File */
```

Listing 9 *Preprocessed results from Listing 8*

```
"VERSION"
"2"
VERSION3
23
2
VERSATILE

"This is version ""2"
"version2" ".h"
"INCFILE(VERSION)"
"\"version2\" \".h\""
```

C++'s preprocessor isn't much different than C's, you may want to *use* it a lot differently. For example, as far as I can tell, there is no good reason to define object-like macros anymore. You should use *const* variable definitions instead. The statement

```
const int MAXLINES = 500;
```

has a couple of advantages over

```
#define MAXLINES 500
```

Since the compiler knows the semantics of the object, you get stronger compile-time type checking. You can also reference *const* objects like any other with a symbolic debugger. Global *const* objects have internal linkage unless you explicitly declare them *extern*, so you can safely replace all your object-like macros with *const* definitions.

Function-like macros are *almost* unnecessary in C++. You can replace most function-like macros with inline functions. For example, replace the *max* macro as shown previously with

```
inline int max(int x, int y)
{
    return x >= y ? x : y;
}
```

Note that you don't have to worry about parenthesizing to avoid precedence surprises, because this code defines a real function, with scope and type checking. You also don't have to worry about side effects like you do with macros, such as in the call

Table 4 *Trigraph sequences*

Trigraph	C Source Character
??=	#
??(	[
??/	\
??)	]
??'	^
??<	{
??!	|
??>	}
??-	~

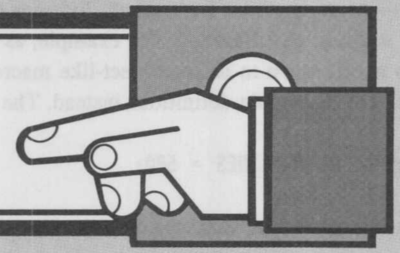
Table 5 *New C++ digraphs and identifiers*

Token	Translation
<%	{
%>	}
<:	[
:>	]
%%	#
bitand	&
and	&&
bitor	|
or	||
xor	^
compl	~
and_eq	&=
or_eq	|=
xor_eq	^=
not	!
not_eq	!=

The C Users Journal™

Advanced Solutions for C/C++ Programmers

Advertiser Index



Advertiser	Reader Service #	Pg. #
AccuSoft Corporation	140	24
ADONTEC GmbH	**	95
Advanced Design Solutions	242	92
AIB Software	150	58
AnSoft, Inc.	307	141
ARIS	135	143
Austin Code Works	313	62
AYECO, Inc.	399	143
Az-Tech Software, Inc.	245	139
Been There - Done That Software	315	139
Berard Software Engineering, Inc.	192	34
Berard Software Engineering, Inc.	216	141
Borland International	465	11
Brightwork	269	143
Bristol Technology, Inc.	309	42
Bristol Technology, Inc.	259	16
Burton Systems Software	430	31
Byte Dynamics, Inc.	125	144
Bytech Business Systems	229	59
C Associates	137	140
CAD-UL GmbH	209	96
Catenary Systems	253	90
C_Graph Software, Inc.	261	144
ChipTools, Inc.	**	138
Chirp Technical Services	**	142
CMX Company	325	144
Cobalt Blue, Inc.	105	37
Computer Language Arts, Inc.	440	98
Courseware Applications, Inc.	130	143
Creative Programming	123	63
Crystal Software, Inc.	**	53
CUG CDRoms	251	124
CUG Directory IV	277	60
C User's Bookstore	153	81
Datalight	256	84
DBx, Inc.	207	54
DC Micro Development	152	138
DCW Group	**	138
DDC International	218	14
Diab Data, Inc.	154	20
Digital Computing System	122	139
D&L OnLine, Inc.	301	143
DMARZ Diversified Sciences Co.	310	139
Eagle Software, Inc.	183	72
E-Data Link	181	142
EliaShim Microcomputers, Inc.	144	53
Ematek GmbH	219	28
Embedded System Products, Inc.	380	127
Emerald Bay Group	296	104
Emerging Technology	111	113
EMS	281	142
FairCom	128	CIV
Fidelity Investments	**	23
Flanster Software	258	138
FlashTek, Inc.	276	64
Fortunel Systems, Inc.	312	125
General Software, Inc.	320	93
General Software, Inc.	321	40
Gimpel Software	**	97
Gimpel Software	**	109
Gotoless Conversion	**	143
Green Hills Software, Inc.	235	27
Greenleaf Software Inc.	240	CII
Ted Gruber Software	174	18
Illustrated C	496	102
ImageSoft, Inc.	177	139
IMCSI	170	139
Information Modes	118	66
Innovative Software	223	39
InstantInfo Index	**	135
Intelligent Solutions Inc.	184	141
Intelligent Systems Int'l	206	88
Interactive Instruments	120	116
International Computer Prof. Assoc.	108	140
Intertech, Inc.	318	129
InTrepid Software	270	123
ITI Logiciel	**	141
Just Logic Technologies, Inc.	295	99
KADAK Products Ltd.	**	43
Linux Systems Laboratories	158	107
Little Wing	119	130
Machine Independent Software	180	108
Mark Williams Company	**	1
MarshallSoft Computing, Inc.	112	140
μC/OS	127	79
Micro Digital, Inc.	202	114
Micro-Processor Services, Inc.	162	141
MicroQuill Software Publishing	**	140
Microsoft Corp.	**	2
Microware Sas	204	49
MIX Software	236	105
MIX Software	146	111
MMC AD Systems	134	141
Network Dynamics	132	139
Nu-Mega Technologies	**	16a
Object Management Laboratory	106	29
Object Oriented Software Engineering	196	116
Omega Point, Inc.	136	57
On Line Magazine Index	**	78
On Time Marketing	214	56
Opt-Tech Data Processing	203	141
OPUS Software	159	87
Pacific Softworks	494	139
Paladin Software, Inc.	227	100
Parsifal Software	300	141
Powersoft Corporation	**	32
Professional Publications	317	139
ProtoView Development Corp.	376	15
QNX Software Systems, Ltd.	224	41
Quadron	291	143
Quarterdeck Office Systems	201	13
Raleigh Group International	193	45
Ready-To-Run Software, Inc.	155	25
Realtime Control, Inc.	191	138
Rogue Wave Associates	124	9
Ryle Design	110	74
Scientific Endeavors	172	12
SeaBreeze Software Systems	283	110
Sequiter Software, Inc.	257	CIII
SET Laboratories, Inc.	210	86
Sigma Software, Inc.	114	144
S.I.P. - Software Solutions	230	36
SLR Systems, Inc.	268	73
SofDesign International	263	61
SofDesign International	215	68
Softronic GmbH	225	17
Software Blacksmiths, Inc.	147	103
Software Blacksmiths, Inc.	142	143
Software Frontiers	282	142
The Software Group	190	75
Software Interphase	220	22
Software Science, Inc.	324	51
Softway, Inc.	186	8
Spider Software	323	143
Strategic Software Designs Inc.	387	38
StratosWare Corporation	284	7
Sub Systems, Inc.	452	69
The Symmetry Group	316	85
T & T Computer Products	247	52
Technosoft	250	57
Tics Realtime	308	30
Trio Systems	**	67
Valois Software	287	144
Voice Information Systems, Inc.	238	141
Walnut Creek CDROM	131	107
Willies' Computer Software Co.	304	55
Windbase Software	178	89
Windows Custom Controls	278	128
Windows/DOS Developer's Journal	**	121
XVT Corporation	197	19
Zinc Software	126	6

This index is provided as a service to our readers. The publisher assumes no liability for errors or omissions.

***This advertiser prefers to be contacted directly.*

```
max(x++,y++)
```

The macro version may seem superior to the inline function because it accepts arguments of any type. No problem. Define *max* as a template, as in the following code; now the inline function will accept arguments of any type:

```
template<class T>
inline int max(const T& x, const T& y)
{
    return x > y ? x : y;
}
```

Do keep in mind, however, that `inline` is a only *hint* to the compiler. Not all functions are amenable to inlining, especially those with loops and complicated control structures. Your compiler may tell you that it can't inline a function. Still, in many cases it is better to define a function out-of-line than to define it as a macro and lose the type safety that a real function affords.

There is still room in C++ for function-like macros that use the stringizing or token-pasting operators. The program in Listing 13 uses stringizing and an inline function to test the new string class available with Borland C++ 4.0.

Conclusion

The preprocessor doesn't know C or C++. It is a language all its own. Many library vendors have used the preprocessor intelligently to simplify the installation and use of their products. I encourage you to use it, but to use it prudently. It has some dark corners, which I've purposely avoided. It is good practice, especially with C++, to do as much as you can in the programming language, and use the preprocessor only when you need to. □

Listing 10 *A "Hello, world!" program*

```
/* hello.c: Greet either the user or the world */
#include <stdio.h>

main(int argc, char *argv[])
{
    if (argc > 1 && argv[1] != NULL)
        printf("Hello, %s!\n",argv[1]);
    else
        printf("Hello, world!\n");
    return 0;
}

/* End of File */
```

Listing 11 *"Hello, World!" using trigraphs*

```
/* thello.c:    Greeting program using trigraphs */
#include <stdio.h>

main(int argc, char *argv??(??))
??<
    if (argc > 1 && argv??(0??) != NULL)
        printf("Hello, %s!??/n",argv??(1??));
    else
        printf("Hello, world!??/n");
    return 0;
??>

/* End of File */
```

Listing 12 *"Hello, World!" with the new C++ digraphs and tokens*

```
/* dhello.c:    Greeting program using C++ digraphs */
#include <stdio.h>

main(int argc, char *argv<::>)
<%
    if (argc > 1 and argv<:0:> != NULL)
        printf("Hello, %s!??/n",argv<:1:>);
    else
        printf("Hello, world!??/n");
    return 0;
%>

/* End of File */
```

```
// tstr.cpp:      Test the C++ string class

#include <iostream.h>
#include <stddef.h>
#include <cstring.h>

// Handy display macros
#define result(exp)
   cout << #exp ":   \"" << (exp) << '\"' << endl
#define test(obj,exp) \
   exp, print(#obj ", after " #exp ":\n",obj)

// Print a string in quotes
inline void print(const char *p, const string& s)
{
   cout << p << '"' << s << '"' << endl;
}

main()
{
   string s1("Now is the time for all worthy carbon units"),
          s2 = "to come to the aid of their sector.",
          s3 = '\n',
          s4(s1);
   size_t len = s1.length();

   // Test some operators
   result(s1 == s4);
   result(s1 < s4);
   result(s1 + s3 + s2);
   test(s1,s1 += s3 + s2);
   result(s1 == s4);
   test(s1,s1.resize(len));
   result(s1 == s4);
   cout << endl;

   // Search and replace
   size_t pos = s1.find("all");
   if (pos != NPOS)
      test(s1,s1.replace(pos,3,"some"));
   pos = s1.find("worthy");
   if (pos != NPOS)
   {
      result(s1.substr(pos,5));
      test(s1,s1.insert(pos,"un"));
   }
   cout << endl;

   // More searching
   result(s1.find_first_of("aeiou"));
   result(s1.find_first_not_of("aeiou"));
   result(s1.find_last_of("aeiou"));
   result(s1.find_last_not_of("aeiou"));
   cout << endl;

   // Subscripting
   pos = s2.find_first_of('d');
   test(s2,s2[pos] = 'l');
   return 0 ;
}

/* Output:
s1 == s4:  "1"
s1 < s4:  "0"
s1 + s3 + s2:  "Now is the time for all worthy carbon units
to come to the aid of their sector."
s1, after s1 += s3 + s2:
"Now is the time for all worthy carbon units
to come to the aid of their sector."
s1 == s4:  "0"
s1, after s1.resize(len):
"Now is the time for all worthy carbon units"
s1 == s4:  "1"

s1, after s1.replace(pos,3,"some"):
"Now is the time for some worthy carbon units"
s1.substr(pos,5):  "worth"
s1, after s1.insert(pos,"un"):
"Now is the time for some unworthy carbon units"

s1.find_first_of("aeiou"):  "1"
s1.find_first_not_of("aeiou"):  "0"
s1.find_last_of("aeiou"):  "43"
s1.find_last_not_of("aeiou"):  "45"

s2, after s2[pos] = 'l':
"to come to the ail of their sector."
*/

// End of File
```

Title:	*C Elements of Style The Programmer's Style Manual for Elegant C and C++ Programs*
Author:	Steve Oualline
Publisher:	M&T Books 411 Borel Ave, Suite 100 San Mateo, CA 94402 1992
Price:	$21.95
Pages:	265
ISBN:	1-55851-291-8

C Elements of Style

reviewed by Dwayne Phillips

Steve Oualline's *C Elements of Style* is, as its name suggests, a style manual for C programming. Oualline outlines a method for writing clear and decipherable C code. He emphasizes a simple and straightforward style. In his words, this book is for programmers "who want their programs to be easily read and maintained by others."

Audience

You do not need to be a C wizard to understand this book. In fact, wizards who write statements like:

```
*destination++ = *source++
```

may not like this book. Oualline advocates the more accessible:

```
*destination = *source; destination++; source++;
```

If you write programs that must be corrected or augmented by others, this book will be of interest to you. It is especially appropriate for relatively new programmers who are struggling to learn good C programming habits.

Contents

C Elements of Style has nine chapters, a compact style manual, two appendices, and an index. The chapters cover the topics expected in this type of book. They include (1) style and program organization, (2) file basics, comments, and program headings, (3) variable names, (4) statement formatting, (5) statement details, (6) the preprocessor, (7) C++ style, (8) directory organization and makefile style, and (9) user-friendly programming.

For much of the book, Oualline gives examples of good and bad code, and summarizes with style rules. His rules are simple and easy to apply. Some of the rules apply to the process of writing code. For example, "Comment your code as you write it." (This rule, he says, saves time in the long run.) Other rules address the code itself: "Constant names are all upper case" and "Follow every variable declaration with a comment that defines it." Some rules just make a programmer's life easier: "Assume that *, /, and % come before + and –. Put parentheses around everything else."

The style rules are aimed at making programs readable and reliable. Good variable and subroutine names, which help make the code explain itself, and good comments, which help reveal the organization of programs, enhance readability. Oualline strives to increase reliability by limiting the code to safe subsets of the C language. (Not allowing shortcuts such as `*destination++ = *source++` reduces the risk of problematic side effects.) Oualline describes this emphasis on readable and reliable code as "defensive programming" or "doing a lot of thinking so I don't have to do a lot of thinking."

The chapter on makefile style is outstanding and to my knowledge unique. Makefiles are essential to C programming and are often the hardest part of a project to understand. Other books describe how to use makefiles, but this is the only book I have seen that tells how to organize and format them. Oualline formally defines many makefile items that have become pseudo standards over the years. This material may seem trivial to an experienced UNIX C programmer, but many C programmers today have never worked on a UNIX system (believe it or not).

The chapter on user-friendly programming is a bit out of place, but useful. It discusses how to write programs that users will actually use. (It includes the Law of Least Astonishment: The program should act in a way that least astonishes the user.)

Dwayne Phillips works as a computer and electronics engineer with the U.S. Department of Defense. He has a PhD in Electrical and Computer Engineering from Louisiana State University. His interests include computer vision, artificial intelligence, software engineering, and programming languages.

The style manual is 35 pages of rules without all the discussion. For those short on time, this book-within-a-book provides a concise summary of the text.

The first appendix shows three complete code examples (two in C, one in C++) that employ the style rules given in the body of the book. These examples show Oualline's recommendations in practice. The second appendix lists all the rules given in the chapters. (Take these seven pages and pin them on the wall next to the coffee machine.)

Other Style Manuals

For years, the only programming style manual available was Kernighan and Plauger's thin little classic *The Elements of Programming Style* [1]. Fortunately, several style manuals have appeared in the recent past — each written with a different point of view.

Plum's *C Programming Guidelines* [2] and *C++ Programming Guidelines* [3] (reviewed in *The C Users Journal*, January 1993) are comprehensive references on programming standards and style. They are written in a compact, subroutine-like style that is appropriate for reference books. These books are technical and not for the novice.

Steve McConnel's *Code Complete* [4] is a comprehensive handbook for programmers. As such, it includes plenty of good advice on programming style, but its style sections are scattered throughout the 800-plus pages.

While Oualline favors code that anyone can understand, Ranade and Nash's *The Elements of C Programming Style* [5] (reviewed in *The C Users Journal*, July 1993) encourages programmers to master and exploit the notation of the C language. (Ranade and Nash's do recommend backing away from terse C style if the audience includes programmers who have a limited knowledge of C.)

Conclusion

Oualline's book is the closest to Kernighan and Plauger's and it serves as a worthy update to that earlier classic. It is a short, yet complete treatment of C style.

C Elements of Style is a deserving addition to the desk top — not just the bookshelf. □

References

[1] *The Elements of Programming Style*, second edition, Brian W. Kernighan, P.J. Plauger, McGraw Hill, New York, New York, 1978, ISBN 0-07-034207-5.

[2] *C Programming Guidelines*, second edition, Thomas Plum, Plum Hall Inc., ISBN 0-911537-07-4.

[3] *C++ Programming Guidelines*, Thomas Plum and Dan Saks, Plum Hall Inc., ISBN 0-911537-10-4.

[4] *Code Complete, A Practical Handbook of Software Construction*, Steve McConnel, Microsoft Press, One Microsoft Way, Redmond, Wash. 98052-6399, ISBN 1-55615-484-4.

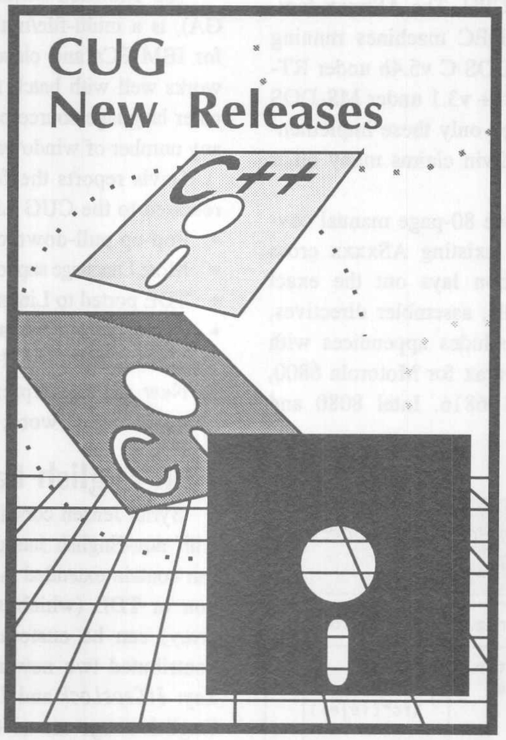
[5] *The Elements of C Programming Style*, Jay Ranade and Alan Nash, McGraw Hill, New York, New York, 1993, ISBN 0-07-051278-7.

Victor R. Volkman

IOCCC, ASXXXX, MINED, TDE Update, and a Bug Fix

CUG Library Volume IV

CUG Library proudly announces volume IV of its directory of user-supported C source code. This latest effort thoroughly catalogs CUG Library volume numbers #300 through #349. Volume IV includes both exhaustive reviews of selected volumes plus capsule summaries of all volumes. In all, this amounts to more than 250 cross-referenced and indexed pages of information. Volume IV can be yours for $10 or order the set of volumes I through IV for just $28 total. As always, see the order blank in the center portion of this issue.



Bug Fix for GNUPlot, CUG #334

Arild Olsen *<d_olsen_o@kari.uio.no>* writes:

"I just received the disk, and the HPLJII-driver does not function, as stated by R.T. Stevens in his review (CUJ, June 93). Maybe this is due to an incompatibility between HP LaserJet II and III; I have a LJ III. When sending a bitmap to the printer, the program specifies TIFF-format. This is not correct since the bitmap is plain.

To solve this, edit the `HPLJIItext` function in the HPLJII driver. The string `"\033*b2m%dW"` should be changed to `"\033*b0m%dW"`.

New Acquisitions and Updates

This month we present three additions to the CUG Library, as well as an update to a recently featured volume.

- International Obfuscated C Code Contest (CUG #397)
- ASxxxx Cross Assembler - Part 3 (CUG #398): MC 68HC08 CPU support
- MINED Editor: (CUG #399)
- Thomson-Davis Editor (CUG #386 update): multi-window text/binary file editor — new version 3.2A

International Obfuscated C Code Contest 1984-1993: CUG #397

Landon Noll (Sunnyvale, CA) submits a decade of source code from the International Obfuscated C Code Contest (IOCCC). This contest has long been a favorite of many *CUJ* readers. The entire IOCCC archive from 1984-1993 is now available as a two-diskette set from the CUG Library. Obfuscation implies purposefully obscuring and confusing a situation. Why obfuscate C code? The official IOCCC states its objectives as follows:

- To show the importance of programming style, in an ironic way.
- To *stress* C compilers by feeding them unusual code.
- To illustrate some of the subtleties of the C language.
- To provide a safe forum for poor C code.

Recently, Bob van der Poel reviewed Don Libes' book entitled *Obfuscated C and Other Mysteries* (see *CUJ*, October 1993, pp. 131-132). The diskette for this book includes IOCCC entries from 1984-1991. Libes has produced special reports about the IOCCC several times in *CUJ*. Please see the following back issues for more detail:

Libes, Don. "Don't Put This on Your Resume," *CUJ*, May 1991, p. 89.

Libes, Don. "The Far Side of C," *CUJ*, May 1990, p. 125.

Libes, Don. "The International Obfuscated C Code Contest," *CUJ*, July 1989, p. 93.

The CUG Library volume #397 contains the full IOCCC archive including two additional years not included in the Libes' book.

Victor R. Volkman received a BS in Computer Science from Michigan Technological University. He has been a frequent contributor to The C Users Journal *since 1987. He is currently employed as Senior Analyst at H.C.I.A. of Ann Arbor, Michigan. He can be reached by dial-in at the HAL 9000 BBS (313) 663-4173 or by Usenet mail to* sysop@hal9k.com.

In addition to dozens and dozens of obfuscated C programs, the archive includes complete rules and guidelines so you can submit your own entries into next year's contest. Some of the obfuscated programs are quite useful, including scaled-down versions of make, grep, and various editors.

ASxxxx Cross Assembler - Part 3: CUG 398

Cross assemblers continue to play an important role in the CUG Library. A cross assembler reads assembly language source code for a non-native CPU and writes object code that can be linked and downloaded to the target machine for execution. Embedded systems developers are the most frequent users of cross assemblers. This month, Alan R. Baldwin (Kent State University, Ohio), adds his third cross assembler to the CUG Library's repetoire. ASxxxx Part 3 provides a complete Motorola 68HC08 development system. ASxxxx Part 3 version 1.50 (released 8/9/93) is immediately available as CUG volume #398.

The CUG distribution of ASxxx Part 3 includes MS-DOS executables for the ASxxxx Cross Assembler and Linker. However, if you want to recompile the Cross Assembler or Linker, you'll also need ASxxxx Part 1 (CUG #292). ASxxx Part 2 contains cross assembler source files for the 6816 CPU. The ASxxxx family of cross assemblers can be built on DEC machines running DECUS C in the TSX+ environment or PDOS C v5.4b under RT-11. ASxxxx has been built with Borland C++ v3.1 under MS-DOS and includes a project (.PRJ) file. Although only these implementations have been specifically tested, Baldwin claims many other K&R C compilers may work as well.

ASxxxx Part 3 includes a comprehensive 80-page manual covering functionality provided by all three existing ASxxxx cross assemblers and linkers. The documentation lays out the exact specifications of syntax for symbols, labels, assembler directives, and expressions in detail. The manual includes appendices with instruction set highlights and supported syntax for Motorola 6800, 6801, 6804, 6805, 68HC08, 6809, 6811 6816, Intel 8080 and 8085, and Zilog Z80 and HD64180 CPUs.

Table 1 *Regular Expression operator precedence: (based on the table in Dr. Aho's book)*

<table>
<tr><th colspan="3">c = char   x = string   r,s = regular expression</th></tr>
<tr><td>c</td><td>any non-operator character</td><td>Felis</td></tr>
<tr><td>\c</td><td>c literally and C escapes</td><td>catus\.</td></tr>
<tr><td>\:c</td><td>predefined macro:
\:a - alphanumeric
\:b - white space
\:c - alphabetic
\:d - decimal
\:h - hex
\:l - lower alpha
\:u - upper alpha</td><td>\:c*(ie|ei)</td></tr>
<tr><td>.</td><td>any character but newline</td><td>c.t</td></tr>
<tr><td><</td><td>beginning of word</td><td><cat</td></tr>
<tr><td>></td><td>end of word</td><td><cat></td></tr>
<tr><td>^</td><td>beginning of line</td><td>^cat></td></tr>
<tr><td>$</td><td>end of line</td><td>cat$</td></tr>
<tr><td>[x]</td><td>any character in x</td><td>[a-z0-9]</td></tr>
<tr><td>[^x]</td><td>any character not in x</td><td>[^AEIOU]</td></tr>
<tr><td>r*</td><td>zero or more r's</td><td>ca*t</td></tr>
<tr><td>r+</td><td>one or more r's</td><td>ca[b-t]+</td></tr>
<tr><td>r?</td><td>zero or one r</td><td>c.?t</td></tr>
<tr><td>rs</td><td>r followed by s</td><td>^$</td></tr>
<tr><td>r|s</td><td>either r or s</td><td>kitty|cat</td></tr>
<tr><td>(r)</td><td>r</td><td>(c)?(a+)t</td></tr>
</table>

The ASxxxx assembler falls short of full macro implementation, but does include a host of important features such as: if/then/else, `#include` files, radix support from binary to hexadecimal, and a full complement of C-language operators for expressions. The ASxxxx linker goes beyond conventional loaders by resolving intermodule symbols, combining code into segments, relocating absolute symbols and base addresses, and producing either Intel HEX or Motorola S19 output files.

MINED Editor: CUG #399

MINED, by Thomas Wolff (Freie Universität Berlin, Institut für Informatik, Germany), is a modeless full-screen text editor. MINED was originally written for MINIX and now works with most UNIX platforms as well as MS-DOS, and DEC VAX-11/VMS. MINED works best at editing small files (50K or less) and can edit many files simultaneously. Unlike other editors which have separate command modes and input modes, MINED uses a modeless design for ease of use. It also includes powerful regular expression operations for both searching and replacing text. MINED Version 3 (released 08/04/93) is immediately available as CUG volume #399.

Thompson-Davis Editor Update: CUG #386

The Thomson-Davis Editor, as provided by Frank Davis (Tifton, GA), is a multi-file/multi-window binary and text file editor written for IBM PCs and close compatibles. Thomson-Davis Editor (TDE) works well with batch files, binary files, text files, and various computer language source code files. TDE can handle any size of file and any number of windows that fit in conventional DOS memory.

Davis reports the following enhancements since TDE was last released to the CUG Library:

- Pop-up pull-down command menu = <CTRL>+\
- More Language support, thanks to Byrial Jensen, `<byrial@daimi.aau.dk>`
- TDE ported to Linux (POSIX, SVR4, BSD4.3+?, FIPS 151-1, etc.)
- A bug (a blunder, actually) got fixed in the 3.1 config utility.
- Linux FAQs and HOWTOs
- New regular expression meta characters: < = Empty string at beginning of word; > = Empty string at end of word

Non-English Language Support

Byrial Jensen contributed several functions to TDE that are useful with non-English languages. Using these functions, DOS filenames can contain extended ASCII characters. As a result, the `dirlist` function in TDE (which sorts filenames according to the sort order array) can be customized to your favorite alphabet. Byrial also contributed two new macro functions that look at the Caps Lock key: `IfCapsLock` and `IfNotCapLock`. Other changes supporting non-English usage are as follows: predefined regular expression macros may be redefined; all editor prompts have been gathered into `prompts.h`; response letters have been gathered into `letters.h`; and the window letters can be changed to follow a non-English alphabet.

Improved Regular Expression Handling

Davis writes: "I use the regular expression search much more often than I first anticipated. A couple of features missing in the original implementation are the beginning-of-word and end-of-word metacharacters. These metacharacters really come in handy for culling prefixes and suffixes from the search. Here's our new regular expression table: [Please refer to Table 1]"

TDE version 3.2a (Released 11/15/93) immediately replaces version 3.0 and is available as CUG Library volume #386. □

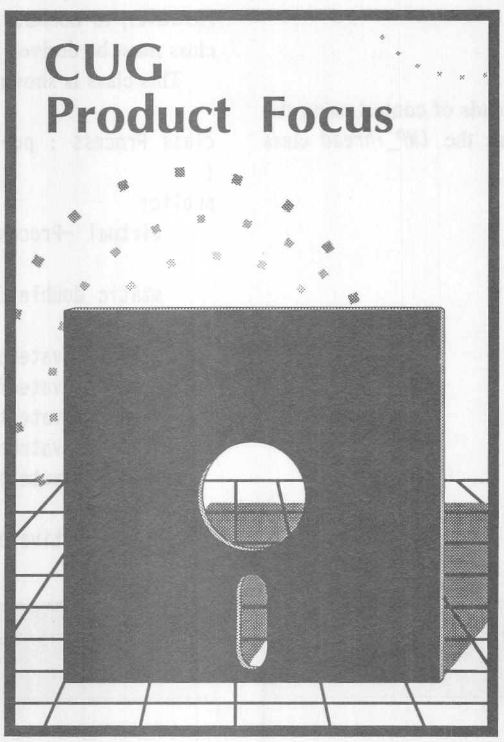
Victor R. Volkman

C++ SIM

Introduction

This month's product focus is derived from documentation written by M.C. Little and D.L. McCue. Little and McCue have provided this documentation, which describes their C++ SIM simulation class library, expressly for reprint in The *C Users Journal*.

C++ SIM is a class library which provides discrete process-based simulation similar to that provided by SIMULA [Birtwhistle 73][Dahl 70] and has been used in the work presented in [McCue 92]. Based on the facilities provided in SIMULA, C++ SIM provides active objects (instances of C++ classes) as the units of simulation using the type-inheritance facilities of C++ to convey the notion of "activity."



C++ SIM is designed to be used with a user-supplied threads package. C++ SIM's authors use Sun Microsystem's lightweight process (thread) package; however, they have added this package to the simulation class hierarchy through an abstract class definition so that other lightweight process packages can be used instead with very little modification. Users of this framework can replace existing classes as long as the replacements conform [Black 86] to the original class definition.

This article describes the C++ SIM class hierarchy, and shows how it can be used to further refine the simulation package [1].

The Class Hierarchy

Figure 2 illustrates the main class hierarchy within the simulation package. The base class is *Thread*, which provides the minimum functionality required of a threads library. Two classes, *GNUThread* and *LWP_Thread*, derive from the *Thread* class to support the threads packages that were available to C++ SIM's authors at the time of this writing. These classes are Sun's own lightweight process package, and the GNU threads library. Class *Thread_Type* provides a (relatively) transparent way to change from one thread implementation to another. Class *Process* provides all operations required by the simulator to control execution of all processes in the simulation. These classes are described in the following sections.

The Threads Base Class

In keeping with the C++ programming model, classes obtain the thread characteristic, necessary to convey the notion of "activity" within the simulation environment, by inheriting an appropriate base class (in simulation terms they become processes). In C++ SIM, all classes that provide the abstraction of threads must be derived from the *Thread* base class. This base class forces the derived class to provide a minimum set of operations required for the management of threads. (The base class defines these operations as pure virtual functions, and C++ requires that a deriving class define such functions before an instance of the class can be declared.) These operations are shown in the *Thread* class as follows:

```
class Thread
{
public:
     virtual void Suspend() = 0; // pure virtual function
     virtual void Resume() = 0;
```

Victor R. Volkman received a BS in Computer Science from Michigan Technological University. He has been a frequent contributor to The C Users Journal *since 1987. He is currently employed as Senior Analyst at H.C.I.A. of Ann Arbor, Michigan. He can be reached by dial-in at the HAL 9000 BBS (313) 663-4173 or by Usenet mail to* sysop@hal9k.com.

```
    virtual long Identity();
    static Thread* Self();
};
```

When defined, the *Suspend* and *Resume* methods will give the thread package specific ways of suspending and resuming execution of a thread respectively.

Body represents the controlling code for each object, i.e., the scope within which the controlling thread will execute.

Current_Thread must be defined by the derived class, since it returns the identity of the currently executing thread, which is specific to the thread package used.

The base class itself implements the operations *Identity* and *Self* because some threads packages do not provide similar functionality. *Identity* returns the unique identity of the thread associated with a given object, and *Self* returns the currently executing thread. Because *Self* is a static member function programs can invoke it without creating an instance of the Thread class, i.e., programs may call *Thread::Self()*.

The Class *LWP_Thread*

User classes which require separate threads of control using the Sun thread package can be derived from the *LWP_Thread* class shown as follows:

```
class LWP_Thread : public Thread
{
public:
    virtual void Suspend();
    virtual void Resume();
    virtual void Body() = 0;

    virtual long Current_Thread();

    thread_t Thread_ID();

protected:
    static const int MaxPriority;
    LWP_Thread(int priority = MaxPriority);
};
```

The *MaxPriority* constant represents the maximum priority at which a thread may execute (by default all threads derived from this class execute at this priority). Class *LWP_Thread* defines all of the pure virtual functions declared in *Thread* except *Body*, which must be defined by the deriving class.

Initialize initializes the threads package prior to use. (Obviously the operations performed within this method are thread package specific.)

Thread_ID returns more detailed (package-specific) information about the associated thread.

The Process Class

Applications could derive from the *Thread* base class to provide active objects in C++ outside of the simulation package. However, to become a process in the simulation environment, a class must be derived from the *Process* base class.

This class is shown as follows:

```
class Process : public LWP_Thread
{
public:
    virtual ~Process ();

    static double CurrentTime ();

    void ActivateBefore (Process&);
    void ActivateAfter (Process&);
    void ActivateAt (double AtTime = CurrentTime());
    void ActivateDelay (double AtTime = CurrentTime());
    void Activate();

    void ReActivateBefore (Process&);
```

Figure 1 *Head of simulation queue*

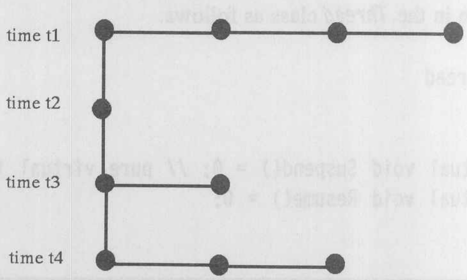
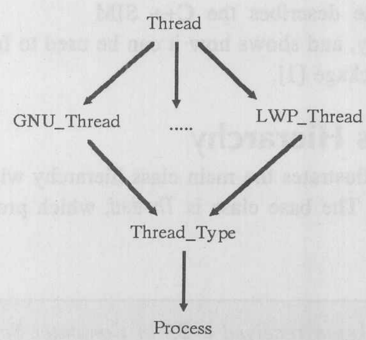


Figure 2 *Simulation class hierarchy*



```
    void ReActivateAfter (Process&);
    void ReActivateAt (double AtTime = CurrentTime());
    void ReActivateDelay (double AtTime = CurrentTime());
    void ReActivate ();

    void Cancel ();
    double evtime ();
    void set_evtime (double);

    boolean idle ();
    boolean terminated ();

    virtual void Body () = 0;

protected:
    Process ();

    void Hold (double t);
    void Passivate ();
};
```

idle returns either TRUE or FALSE depending upon whether the process is currently in the simulation queue.

terminated returns either TRUE or FALSE depending upon whether the process is terminated.

evtime returns the simulation time at which a process is due to be reactivated; *set_evtime* enables a program to change this time.

The *Hold* method removes the active process from the head of the event queue and schedules it to become active a specified number of time units later.

Passivate removes the currently active process from the event queue altogether. If the process is to execute again the program must recreate it.

Cancel removes the process from the simulation queue or simply suspends it indefinitely if it is currently not in the queue.

At any point in time, a process can be in one (and only one) of the following states:

- active: the process is at the head of the queue maintained by the scheduler (to be described shortly) and its actions are being executed.
- suspended: the process is in the queue maintained by the scheduler, scheduled to become active at a specified time in the future.
- passive: the process is not in the scheduler's queue. Unless another process brings it back into the queue, it will not execute any further.
- terminated: the process is not in the scheduler's queue and has no further actions to execute.

There are five ways to activate a process, and similarly five ways to reactivate a waiting process:

- before another process (*ActivateBefore* and *ReActivateBefore*);
- after another process (*ActivateAfter* and *ReActivateAfter*);
- at a specified (simulated) time (*ActivateAt* and *ReActivateAt*);
- after a specified (simulated) delay (*ActivateDelay* and *ReActivateDelay*);
- activate now (at the current simulated time) (*Activate* and *ReActivate*).

(Note that if a process is already scheduled, reactivation will simply re-schedule the process.)

The *CurrentTime* method returns the current simulation time; programs typically call *CurrentTime* to control action relative to a given time period.

The Simulation Scheduler

As in SIMULA, simulation processes (entities) execute at their assigned simulation time, which is typically determined by an appropriate distribution function. Only one process executes in any instance of real time, but many processes may execute at any instance of simulation time. Programs place currently inactive processes in a simulation queue (the event queue), which is arranged in order of increasing simulation time.

To coordinate the execution of these processes, the scheduler manages the simulation queue as follows: when no process is currently active, the scheduler selects a process to run from the head of the queue and (re-) activates it. When no processes are left to execute, i.e., the queue is empty, the simulation ends.

The simulation queue is organized as a tree to improve the efficiency of the scheduling algorithm. All nodes (processes) at the same level of the tree are assigned to the same simulation time, as shown in Figure 1.

Because the scheduler manages processes in the simulation environment it cannot itself be a simulation process. Like the main thread to be described later, the scheduler is a priority thread within the environment and as such must be controlled in a slightly different manner than the other simulation entities. The structure of the scheduler is extremely simple and is shown as follows:

```
class Scheduler : public LWP_Thread
{
public:
    Scheduler ();
    ~Scheduler ();
```

```
    void Body ();
    double CurrentTime ();
};
```

Every simulation application must start one scheduler before the simulation can begin. The example to be described near the end of this article illustrates use of the scheduler.

Priority Threads

C++ SIM executes two "priority" threads which cannot be derived from the *Process* base class and therefore must be activated and deactivated separately. These threads are as follows:

- the simulation scheduler: this thread must be activated via the *Resume* method of the thread base class from which it is derived (e.g., *LWP_Thread*);
- the thread associated with *main*. A program must suspend this thread to allow other threads to run since this thread has the highest priority in the system. Calling the *Thread* class *Initialize* method within the main body of the simulation code adds this thread to the thread queue maintained by class *Thread*. The thread's presence in the queue allows the *Suspend* method to act on it when the program requirs it to become inactive (using the *Thread::Self()->Suspend()* operation).

Distribution Functions

Simulations often require distribution functions of various events (e.g., the rate of arrivals of jobs at a processor, or the time between failures for a node). C++ SIM provides a set of classes which give access to various useful distribution functions, including the following: *RandomStream*, *UniformStream*, *Draw*, *ExponentialStream*, *ErlangStream*, *HyperExponentialStream*, and *NormalStream*. By creating instances of these classes the simulation processes can gain access to the appropriate distribution function. Figure 3 shows the class hierarchy of the distribution functions.

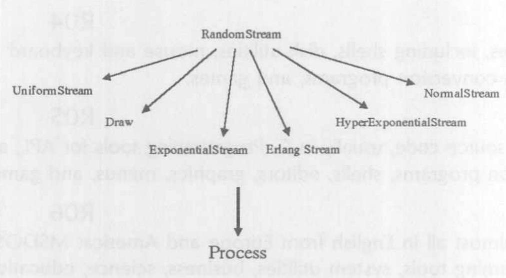
RandomStream and *NormalStream*

Classes *RandomStream* and *NormalStream* illustrate how the distribution functions are derived and show how further functions could be built. *RandomStream* (from which all other distribution functions are derived) is shown as follows:

```
class RandomStream
{
public:
    RandomStream (long MGSeed = 772531L,
                  long LCGSeed = 1878892440L);
    virtual double operator() () = 0;
    double Error ();

protected:
    double Uniform ();

private:
    double MGen ();
    double series[128];
    long MSeed, LSeed;
};
```

The *Error* method returns a chi-square error measure on the uniform distribution function. The *Uniform* method generates random numbers; *Uniform* uses the linear congruential generator based on the algorithm from [Knuth Vol2], and shuffles the results of the linear generator with the multiplicative generator as suggested by [Knuth Vol2] [3] to obtain a sufficiently uniform random distribution.

Figure 3 *Class hierarchy for distribution functions*



```
class NormalStream : public RandomStream
{
public:
    NormalStream (double Mean, double StandardDeviation);
    virtual double operator() ();

private:
    double Mean, StandardDeviation;
    double z;
};
```

The *operator()* uses the polar method in [Knuth Vol2] [4] to implement the *NormalStream* by making use of the *Uniform* method of *RandomStream*.

SIMSET

C++ SIM also provides entity and set manipulation facilities similar to those provided by the *SIMSET* classes of SIMULA. These facilities break down into two classes:

- *Link*: the *Link* class provides elements of a doubly linked list;
- *Head*: the *Head* class maintains doubly linked lists of *Link* elements.

Class link is defined as follows:

```
class Link
{
public:
    virtual ~Link ();

        Link* Suc () const;
        Link* Pred () const;

        Link* Out ();
        void InTo (Head*);

        void Precede (Link*);
        void Precede (Head*);
        void Follow (Link*);
        void Follow (Head*);

protected:
        Link ();
};
```

Because it makes no sense to create instances of *Link* objects, the constructor for *Link* is protected — programs must derive a class from *Link* to benefit from its functionality.

Suc and *Pred* return the successor and predecessor of this list element respectively. These functions return *0* if no such element exists.

Out removes the object to which it currently belongs (if any) from the linked list. *InTo* makes this object the last element in a linked list if the list exists; If the list doesn't exist *Out* attempts to remove the object from any linked list to which it may belong.

Precede also places an object in a linked list. If *Precede* is passed another *Link* element, say *L*, then if *L* is a member of a linked list, this object is placed into the same linked list and immediately preceding *L*. If *L* isn't a member of a linked list, the result is the same as for *Out*. If *Precede* is passed a Head object it produces the same result as *InTo*.

Follow acts similarly to *Precede*, except that *L.Follow(L1)* inserts *L* immediately after *L1*, and *L.Follow(H)*, places *L* as the first element in *H*, where *H* is a Head object.

Note that as in SIMULA, Link elements can only belong to one linked list at a time.

Class *Head* is defined as follows:

```
class Head
{
public:
    Head ();
    virtual ~Head ();

    Link* First () const;
    Link* Last () const;

    long Cardinal () const;
    boolean Empty () const;

    void Clear ();
};
```

First and *Last* return references to the first and last Link objects in the list respectively. If the list is empty then these functions return *0*.

Cardinal returns the number of *Link* objects in the list, and *Empty* returns TRUE if the list is empty, FALSE otherwise. *Clear* removes all *Link* objects from the list.

Example: Job Service Simulation

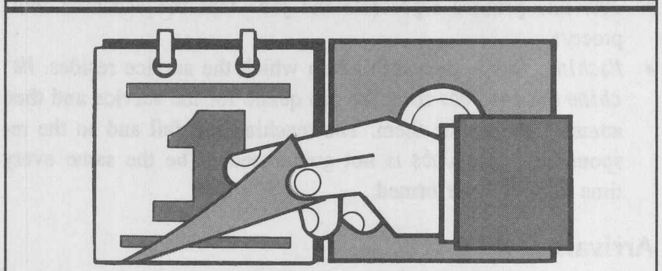
This example is taken from [Mitrani 82] and simulates a process scheduler for a machine which attempts to execute as many process (jobs) as possible. The machine can only process one job at a time and queues job requests until it can deal with them. The machine is prone to failures, so started jobs will be interrupted by such failures and delayed until the machine has been repaired (reactivated), at which point it is forced to restart execution from the beginning (i.e., it is placed at the head of the job queue). The main processes within this example are:

- *Arrivals*: this process controls the rate at which jobs arrive at the service (Machine).
- *Breaks:* this process controls the availability of the Machine by "killing" it and restarting it at intervals drawn from a *Uniform* distribution.
- *Job*: this process represents the jobs that the Machine must process.
- *Machine:* this is the machine on which the service resides. *Machine* obtains *Jobs* from the job queue for the service and then attempts to execute them. The machine can fail and so the response time for *Jobs* is not guaranteed to be the same every time the job is performed.

Arrivals

The Arrivals class definition is relatively simple since none of the other processes invoke operations on it. *Arrivals* is defined as follows:

```
class Arrivals : public Process
{
public:
    Arrivals (double);
    ~Arrivals ();

    void Body ();

private:
    ExponentialStream* InterArrivalTime;
};
```



Calendar of Events

April

18-21 *ISCA '94: 21st International Symposium on Computer Architecture.* Chicago, IL. Sponsored by ACM special interest group ARCH and the IEEE-TC CA. Contact Wen-mei Hwu, Coordinated Science Laboratory, 1308 W. Main Street, Urbana, IL 61801. (217)-244-8270. e-mail: `hwu@crhc.uiuc.edu`.

19-21 *Embedded Systems Conference East.* Boston, MA. Contact Amy Royer, Embedded Systems Conference, 600 Harrison St., San Francisco, CA 94107. (415)-905-8198.

24-28 *CHI '94: ACM Conference on Human Factors in Computer Systems.* Boston, MA. Sponsored by ACM special interest group CHI. Contact Thomas Hewett, Drexel University, Dept. of Psych/Soc/Anthro, Central Receiving, 33rd & Ludlow Streets, Philadelphia, PA 19104. (215)-590-8616, 8672. e-mail: `hewett.chi@xerox.com`.

May

17-20 *CoopIS-94:Second International Conference on Cooperative Information Systems.* Formerly "Intelligent & Cooperative Information Systems (ICICIS)." Toronto, Canada. Contact John Mylopolous, (416)-978-5180. e-mail: `coopis@cs.toronto.edu`.

23-25 *Symposium on Theory of Computing.* Montreal, Canada. Sponsored by ACM special interest group ACT. Contact Pierre McKenzie, Dept. IRO, Universite de Montreal, C.P. 6128 succursale A Montreal, Quebec H3C 3J7 CANADA. (513)-343-6176. e-mail: `mckenzie@iro.umontreal.ca`.

June

9-11 *The Grace Hopper Celebration of Women in Computing.* Washington, D.C. Sponsored by ACM and CRA, the Computing Research Association. Contact Anita Borg, Digital Equipment Corp., 250 University Ave., Palo Alto, CA 94301. (415)-688-1367. e-mail: `borg@pa.dec.com`.

25-26 *5th International Workshop on ML and its Applications.* Orlando, FL. Sponsored by ACM special interest group PLAN. Contact John Reppy, AT&T Bell Laboratories, 600 Mountain Avenue, Rm. 2A-428, Murray Hill, NJ 07974. (908)-582-4084. e-mail: `jhr@research.att.com`.

26-29 *6th Annual ACM Symposium on Parallel Algorithms and Architectures.* Cape May, NJ. Sponsored by ACM special interest groups ACT and ARCH. Contact Satish Rao, NEC Research Institute, 4 Independence Way, Princeton, NJ 08540. (609)-951-2714. e-mail: `satish@research.nj.nec.com`.

The constructor initializes the stream from which the rate of *Job* arrivals is drawn and the destructor simply cleans up before the object is destroyed:

```
Arrivals::Arrivals (double mean)
{
      InterArrivalTime = new ExponentialStream(mean);
}
Arrivals::~Arrivals () { delete InterArrivalTime; }
```

The main body of *Arrivals* (shown below) simply waits for an amount of time dictated by the rate of arrivals stream and then creates another *Job*. This procedure is repeated until the simulation ends.

```
void Arrivals::Body ()
{
      for (;;)                              // inifinite loop
      {
            Hold((*InterArrivalTime)());
            Job* work = new Job();
      }
}
```

Job

Unlike *Arrivals*, which is an active entity within the simulation, the *Job* class does not need to be a separate process, since it is simply enqueued when it is created and dequeued by the *Machine* when it can be executed. All a given *Job* must do is calculate how long it took to be "processed":

```
class Job
{
public:
      Job ();
      ~Job ();

private:
      double ArrivalTime;
      double ResponseTime;
};
```

Because no operations are invoked on instances of the Job class, its constructor and destructor perform all of its work:

```
Job::Job ()
{
      boolean empty;

      ResponseTime = 0;
      ArrivalTime = sc->CurrentTime();
      empty = JobQ.IsEmpty();
      JobQ.Enqueue(this);  // place this Job on to the queue
      TotalJobs++;

      if (empty && !M->Processing() && M->IsOperational())
            M->Activate();  // Machine idle as no Jobs in queue
```

```
                    // and not broken
}

Job::~Job ()
{
    ResponseTime = sc->CurrentTime() - ArrivalTime;
    TotalResponseTime += ResponseTime;
}
```

Queue

The program places jobs which are not being serviced in a job queue. As with the *Job* class, an instance of *Queue* is not required to be active, and as such *Queue* is not derived from the *Process* class.

Queue is defined as follows:

```
class Queue
{
public:
    Queue ();
    ~Queue ();

    boolean IsEmpty ();
    // returns TRUE if no Jobs in queue
    long QueueSize ();
    // returns number of Jobs in queue
    Job* DeQueue ();
    // returns head of queue
    void Enqueue (Job*);
    // places Job at tail of queue
};
```

Machine

The *Machine* process obtains *Jobs* from the queue and processes them. Since *Machine* is prone to failures *Jobs* can take extended periods of time to complete. Other simulation processes invoke various operations on the machine (for example to determine whether or not it has failed):

```
class Machine : public Process
{
public:
    Machine (double);
    ~Machine ();

    void Body ();

    void Broken ();
    void Fixed ();
    boolean IsOperational ();
    boolean Processing ();
    double ServiceTime ();

private:
    ExponentialStream* STime;
    boolean operational;
    boolean working;
};
```

As with the *Breaks* and *Arrivals* processes, *Machine's* constructor and destructor initialize and delete the stream that dictates the time required to process a *Job*.

Processing returns the current status of the machine, i.e., whether or not it is executing a job:

```
boolean Machine::Processing () { return working; }
```

Broken and *Fixed* de-activate (crash) and re-activate the machine respectively:

```
void Machine::Broken () { operational = false; }
void Machine::Fixed () { operational = true; }
```

IsOperational indicates whether or not the machine is currently active (i.e., whether it has "crashed"):

```
boolean Machine::IsOperational () { return operational; }
```

ServiceTime returns the time required to service a given job based on the relevant distribution function initialized within the constructor:

```
double Machine::ServiceTime () { return (*STime)(); }
```

The main body of the *Machine* gets a *Job* from the job queue (if one is available) and attempts to process it before looping again:

```
void Machine::Body ()
{
    for (;;)
    {
        working = true;

        while (!JobQ.IsEmpty())
        // continue as long as Jobs are available
        {
            Hold(ServiceTime());
            Job* J = JobQ.Dequeue();

            ProcessedJobs++;
            // keep track of number of completed Jobs
            delete J;           // remove finished Job
        }

        working = false;
        // no Jobs in queue so become idle
        Cancel();
    }
}
```


Breaks

The Breaks class defines a process which simply waits for a specific period of time before "killing" the *Machine* process. This process then waits again before re-activating the machine. The *Breaks* class definition is relatively simple:

```
class Breaks : public Process
{
public:
    Breaks ();
    ~Breaks ();

    void Body ();

private:
    UniformStream* RepairTime;
    UniformStream* OperativeTime;
    boolean interrupted_service;
};
```

The constructor and destructor simply initialize and delete the streams used by the *Breaks* process respectively.

The main body of the *Breaks* process activates and deactivates the *Machine* process. The *Machine* fails and recovers according to the *OperativeTime* and *RepairTime* distribution functions respectively. The body is defined as follows:

```
extern Machine* M;  // This is the machine used to
                    // service requests
extern Queue JobQ;  // This is the queue from which
                    // Jobs are drawn

void Breaks::Body ()
{
  for (;;)
    {
        Hold((*OperativeTime)());
        M->Broken();
        // de-activate the Machine
        M->Cancel();
        // remove Machine from Scheduler queue

        if (!JobQ.IsEmpty())
            interrupted_service = true;

        Hold((*RepairTime)());
        M->Fixed();    // re-activate the Machine
        if (interrupted_service)
        {
            interrupted_service = false;
            M->ActivateAt(M->ServiceTime() +
                          CurrentTime());
        }
        else
```

```
    M->ActivateAt();
    }
}
```

MachineShop

The *MachineShop* class is the core of the simulation; it starts up all of the main processes involved, and when the simulation ends it prints out the results.

```
class MachineShop : public Process
{
public:
    MachineShop ();
    ~MachineShop ();

    void Body ();
    void Await ();
};
```

The *Body* method starts up the other processes, such as the *Machine*, and then waits until the number of processed *Jobs* is at least 100,000:

```
void MachineShop::Body ()
{
    sc = new Scheduler();          // create the simulation
                                   // queue scheduler
    Arrivals* A = new Arrivals(10);
    M = new Machine(8);
    Job* J = new Job;
    Breaks* B = new Breaks;

    // activate the relevant simulation processes

    B->Activate();
    A->Activate();
    sc->Resume();                  // start up the scheduler
                                   // - it is not a process

    while (ProcessedJobs < 100000)
        Hold(10000);

cout << "Total number of jobs processed "
<< TotalJobs << endl;
cout << "Total response time " << TotalResponseTime << endl;
cout << "Avge response " <<
(TotalResponseTime/ProcessedJobs) << endl;
cout << "Avge number jobs present "
<< (JobsInQueue/CheckFreq) << endl;

    // end simulation by suspending processes

    sc->Suspend();
    A->Suspend();
    B->Suspend();
}
```

It isn't necessary to explicitly activate the *Machine* process because the *Breaks* or *Jobs* process will do this.

The *Await* method suspends the thread associated with *main*, thus allowing the other simulation threads to execute:

```
void MachineShop::Await()
{
    Resume();
    Thread::Self()->Suspend();
}
```

Main

The main part of the simulation code initializes the various thread-specific variables used (e.g., the maximum priority of a thread), creates the main body of the simulation code (in this case *MachineShop*) and then suspends the thread associated with main:

```
void main ()
{
    LWP_Thread::Initialize();

    MachineShop m;
    m.Await();          // Suspend main's thread
                        // (NOTE: this MUST be done
                        // by all applications).
```

}

Conclusions

The authors of C++ SIM have endeavoured to provide a simulation package which provides similar functionality to that of SIMULA, since SIMULA has fulfilled the needs of users over many years. From their experiences of using SIMULA, both as a general programming language and as a simulation tool, they believe they have been successful. As a result of using C++ they also believe that they have produced a simulation package having several advantages over SIMULA, for example:

- performance — C++ compilers typically generate code that is several times more efficient than similar SIMULA code, and as a result, simulations execute correspondingly faster;
- C++ provides more extensive object-oriented features than SIMULA, allowing, for example, class instance variables to be either publicly or only privately available. In SIMULA, everything is public, affecting the way code is written and providing extra problems during debugging.
- C++ SIM incorporates inheritance throughout its design to an even a greater extent than is already provided in SIMULA. For example, C++ SIM's I/O facilities, random number generators, and probability distribution functions are entirely object-oriented, relying on inheritance to specialize their behavior. Hence, users can add new functionality (e.g., new random number generators) with little effect on the overall system structure.

Acknowledgements

The authors would like to thank Professor Isi Mitrani for the help he has given them in the development of this simulation package and the time he has devoted to listening to their thoughts and problems. They would also like to thank Ron Kerr for his help with the SIMULA language, and Dr. Graham Parrington for his comments on drafts of this article. The work reported here has been supported by SERC/MOD Grant GR/H81078 and Esprit Broadcast (Basic Research Project Number 6360). □

References

[Birtwhistle 73] G. M. Birtwhistle, O-J. Dahl, B. Myhrhaug, K. Nygaard, *Simula Begin*, Academic Press, 1973.

[Black 86] A. Black et al, "Object Structure in the Emerald System", *Proceedings of the ACM Conference on Object-Oriented Programming Systems, Languages, and Applications*, October 1986.

[Dahl 70] O-J. Dahl, B. Myhrhaug, K. Nygaard, "SIMULA Common Base Language," Technical Report S-22, Norwegian Computing Centre, 1970.

[Knuth Vol2] Knuth Vol2, *Seminumerical Algorithms*, Addison-Wesley: p. 117.

[McCue 92] D. L. McCue and M. C. Little, "Computing Replica Placement in Distributed Systems," *Proceedings of the 2nd Workshop on the Management of Replicated Data*, November 1992: pp. 58-61.

[Mitrani 82] I. Mitrani, *Simulation Techniques for Discrete Event Systems*, Cambridge University Press, Cambridge, 1982: p. 22.

[Sedgewick 83] R. Sedgewick, *Algorithms*, Addison-Wesley, Reading MA, 1983: pp. 36-38.

[Stroustrup 86] B. Stroustrup, *The C++ Programming Language*, Addison Wesley: 1986.

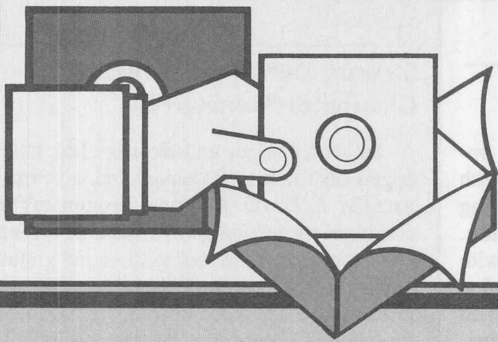
Footnotes

[1] The software to be described in this paper is available via anonymous ftp from `arjuna.ncl.ac.uk`

[2] The authors would like to thank Professor I. Mitrani for his help in developing the multiplicative generator used in the simulation. It is based on the following algorithm: `Y[i+1] = Y[i] * 5^5 mod 2^26`, where the period is *2^24*, and the initial seed must be odd.

[3] As suggested by Maclaren and Marsaglia.

[4] Due to Box, Mullers and Marsaglia



New Products

Industry-Related News & Announcements

Blue Sky Releases Code Generator for OWL v2.0

Blue Sky Software Corporation has released WindowsMAKER Professional v5, a Prototyper and C/C++ code generator for Windows and Windows NT, which lets Borland C++ v4.0 users generate OWL v2.0 code. WindowsMAKER v5 integrates into the Borland IDE and offers 50 features in addition to those offered by AppExpert.

Features of WindowsMAKER v5 include: Visual Basic-like code editing, toolbar, and context-sensitive SmartMenus; a Visual Screen Designer, which includes drag-and-drop editing and a configurable tool palette; and a Preview Mode which lets users preview and test run an application before compiling. WindowsMAKER v5 also includes Switch-It Code Generation Modules (SIMs), which let users switch to any language or major C++ library during the development of an application. Users can choose to automatically generate ANSI C, MFC and OWL from one design. Using WindowsMAKER v5, users can start a project and decide the type of code to use later and target Windows, Win32s, and Windows NT.

Other features of WindowsMAKER v5 include: toolbar support; application templates; code generation for online help; special effect support for fonts, colors, 3D buttons, patterns, and 256-color bitmaps; style and property setting support for controls; MDI application support; and Extended Functionality Modules (EFMs).

WindowsMAKER Professional v5 includes the ANSI C SIM and is $995. Registered users of WindowsMAKER Professional v4 can upgrade for $269. For more information contact *Blue Sky Software Corporation, 7486 La Jolla Blvd., Suite 3, La Jolla, CA 92037, (800) 677-4946 or (619) 459-6365; FAX: (619) 459-6366.*

Select Software Upgrades C++ Designer

Select Software Tools has upgraded C++ Designer, an MS-Windows-based object oriented analysis and design tool, which includes Microsoft's MFC2 Library and the Borland Owl Library. Based on Rumbaugh's Object Modeling Technique (OMT), C++ Designer lets the user structure systems graphically, adding classes and relationships using the GUI. The most recent release allows users to select from classes available in the Microsoft library or from their own class library. Header files for C++ can be generated from the design and linked into the Visual C++ environment.

Features of C++ Designer include: Windows CUA compliance; MDI interface; a data dictionary browsing capability; access control via user-ID; export facility to clipboard or to Windows metafile; project administration including versioning, backup, restore, and off-line; and multi-page printing. C++ Designer also supports the object-oriented and C++ features including: single and multiple-class inheritance; class properties such as attributes and operations; associations including multiplicity, roles, qualifiers, and specialized forms such as aggregations; defining the access, virtual and static nature of attributes and operations, and the access and virtual nature of base classes; and storage of additional descriptive and constraint information for classes, attributes, operations, and associations.

C++ Designer can be integrated with Borland's C++ and Turbo C++, and Microsoft's Visual C++. It can also be configured to integrate with other Windows IDEs. Code frames can also be generated from C++ Designer. Code is compatible with most C++ compilers including Borland, Microsoft, and Clarion TopSpeed.

C++ Designer is $295 per user, including free technical support via a toll free number. Upgrades are sold separately. Users who have purchased C++ Designer within the past three months will receive the MFC2 library at no cost. For more information contact *Select Software Tools, Ltd., 1526 Brookhollow Dr., #84, Santa Ana, CA 92705, (714) 957-6633; FAX: (714) 957-6219.*

National Information Systems Releases ACCENT STP

National Information Systems, Inc. has released ACCENT STP (Sun Transition Pack) v2.0, a source code translator for Sun developers who plan to migrate their OPEN LOOK applications to Motif and the Common Desktop Environment. ACCENT STP supports Motif v1.2 and X11R5 on Sun OS v4.1.x , and Solaris v2.x. According to NIS, ACCENT STP will translate 80% to 100% of the C/C++ application source code produced by XView, OLIT, or Devguide GIL files, including header files, where there are equivalent resources offered in Motif. The translated output will be recognizable Motif C or C++ source code.

Features of ACCENT STP v2.0 include support for "drag and drop," TTY widgets, and internationalization support. Other features of ACCENT STP include: compliance to the Motif standard, compatibility with Solaris v2.4/COSE CDE, and application portability to multiple hardware platforms.

ACCENT STP consists of four optional modules. The Devguide Conversion, XView Conversion, and OLIT Conversion modules are $4,995 each. The WindowMaker GUI Editor is $1,495. Motif consulting and training are also available. ACCENT ToolKit, a Motif library and OPEN LOOK ToolKit which helps support OPEN LOOK users after the source code is translated, is available for $2,495 when purchased with ACCENT STP. For more information contact *National Information Systems, Inc., 4040 Moorpark Ave., Suite 200, San Jose, CA 95117, (800) 441-5758; FAX: (408) 246-3127; e-mail:* `info@nis.com`.

Inmark Releases zApp Interface Pack

Inmark Development Corporation has released the zApp Interface Pack, an add-on product to its C++ class libraries. zApp is a portable

StratosWare Releases MemCheck for ANSI and K&R Platforms

StratosWare Corporation has released an ANSI-compliant source code version of MemCheck, its error-detection tool for C/C++. MemCheck can be used for development projects built with ANSI or K&R compliant C/C++ compilers.

MemCheck for ANSI and K&R can detect memory overwrites and underwrites, memory leaks, heap corruption, and out-of-memory conditions, and requires no source code changes for most projects. MemCheck integrates with existing C/C++ code and works at run time to identify errors by source file and line number. The error messages may be directed to the screen, written to log files, or sent in network or e-mail messages.

MemCheck for ANSI and K&R includes source code and requires no debugging information and no special compilation options. Developers may ship applications with MemCheck linked in, royalty-free, allowing detection of errors at beta or customer sites. According to StratosWare, applications with MemCheck linked in run unchanged and at full speed. MemCheck may be switched on or off at run time, linked out via a "Production" library, or compiled completely out with no source code changes.

MemCheck for ANSI and K&R is $199. StratosWare offers free technical support via fax, CompuServe, Internet, and a toll free number. For more information contact *StratosWare Corporation, 1756 Plymouth Rd., Suite 1500, Ann Arbor, MI 48105, (313) 996-2944; FAX: (313) 747-8519.*

C++ Application Framework that gives application developers cross-platform portability through object-oriented C++ classes. zApp v2.0 is shipping on Windows, Windows NT, DOS Test, DOS Graphics, and OS/2.

The zApp Interface Pack augments zApp by providing a set of additional classes that add graphical elements to applications. Classes in the zApp Interface Pack (ZIP) provide applications with toolbars and status lines, 3D custom controls, bitmap buttons, and a table object.

Quoting Howard Love, President and CEO of Inmark, "Developers can now incorporate the most advanced features of modern applications with just a few lines of code. Toolbars, spreadsheet-like tables, and other high-level controls, which would normally require weeks or months of engineering time, are now available to developers with just a few lines of code."

Demonstration software of zApp is available on the Inmark BBS. For more information contact *Inmark Development Corporation, 2065 Landings Dr., Mountain View, CA 94043, (415) 691-9000; FAX: (415) 691-9099; BBS: (415) 691-9990, CompuServe GO INMARK*

Quadralay Ship UDT for C/C++

Quadralay Corporation has begun shipping UDT for C/C++ v1.2, an open UNIX development environment. UDT for C/C++ works with existing tools and code base, and acts as an incremental front end to existing compilers and other development tools. Features of UDT for C/C++ include: source code browsing, editing, project management, compiling, and prototyping for C++ classes and libraries.

UDT for C/C++ v 1.2 supports SPARC SunOS v4.1.x, SPARC Solaris v2.x, Intel SCO Open Desktop, Intel Solaris v2.x, HP 9000/700, and the RS/6000. UDT for C/C++ v1.2 single and multiple licenses are $595 and $795 per seat respectively. A free, thirty-day evaluation with online documentation is available via anonymous ftp from `ftp.quadralay.com` (192.195.32.1) or by request. For more information contact *Quadralay Corporation, 8920 Business Park Dr., Austin TX 78759, (512) 346-9199; FAX: (512) 794-9997; e-mail:* `info@quadralay.com`.

Sector Seven Releases MakeMaster v2.6

Sector Seven has released MakeMaster v2.6. MakeMaster (formerly DEPGEN), reads C source code and include files to create makefiles. Features of MakeMaster v2.6 include: support for C++, an optimized file search algorithm, flat dependency lists, relative directory references, and custom compiler command lines.

MakeMaster v2.6 supports multiple disk and directory projects, cross-compilers and linkers, libraries, and DLLs. MakeMaster v2.6 runs under DOS v3.3+, and supports ANSI C and C++, Borland's Turbo Make, and Microsoft's NMake. MakeMaster v2.6 is $49.95. For more information contact *Sector Seven, P.O. Box 11391, Burke, VA 22009, (703) 866-9477.*

Stewart, Dufour and Gossage Distributes ProminareTM

Stewart, Dufour and Gossage Ltd. have begun distributing Pominare Inc.'s ProminareTM in North America. ProminareTM combines a graphically oriented GUI design and code generation tool with an integrated development environment and a programming editor. The GUI development part of ProminareTM supports PM controls including those for MMPM/2 and Pen-PM. ProminareTM supports C/C++ compilers and CommonView. The GUI tool also supports direct creation of resource files as well as programming code.

According to the company, the integrated development environment of ProminareTM eliminates most of the common mistakes encountered in trying to build OS/2 applications. ProminareTM's graphical interface supports compiler-independent specification of common options required for compiling and linking programs. The IDE works with the programming editor to manage compiler and linker-detected errors.

ProminareTM's programming editor is PM-based but performs, according to the company, like a character-based editor. The editor is integrated with the IDE and the GUI design tool and provides links to on-line help for the IBM Toolkits. The single-user and network versions of ProminareTM are $895 each. Additional workstation modules are $795. There are no run-time fees or royalties. For more information contact *Stewart, Dufour & Gossage Ltd., 210-1730 Courtwood Cr., Ottawa, Ontario, K2C 2B5, Canada, (613) 225-2121; FAX: (613) 225-2624; BBS: (613) 225-2968.*

DDC International A/S Introduces 1st OBJECT EXEC

DDC International A/S has introduced 1st OBJECT EXEC, a C++-based real-time operating system aimed at industrial use. DDC-I regards C++ as a highly suitable candidate for safely solving control problems, and expects its run-time system to find uses from electronic measuring systems to life and safety-critical appplications. According to DDC-I, their C++ run-time system can facilitate rapid development of complex systems and advanced communications with the switches, sensors, and motors used in new designs.

For more infomation contact *DDC International A/S, Gi. Lundtoftevej 1B, DK-2800 Lyngby, Denmark, +45 45 87 11 44; FAX: +45 45 87 22 17; Telex: 37704 ddci dk.*

Network Dynamics Upgrades Internationalization Toolkit

Network Dynamics has released the Internationalization Toolkit v3.0. The toolkit is used by programmers to simplify and expedite the internationalization/localization of software. Formerly known as "The String Externalization Tools," the toolkit has been expanded to include support for Windows and Presentation Manager string resource files, string length tracking, string file appending, an extraction "undo" utility, string replacement, handling of static initialization, and a graphical user interface.

Version 2.0 features like string extraction, multi-byte Kanji support, software lifecycle support, string tagging, string caching, and string re-insertion have been expanded in version 3.0, with the intent of providing greater flexibility and ease of use. The user's manual has also been expanded. A "white paper" on the subject of software internationalization is available as an option. Sample programs are included to illustrate DOS code page swapping and keyboard manipulation.

The Internationalization Toolkit is available in source code form for C/C++. Plans call for release of Turbo Pascal and Quick Basic versions in 1994. The Internationalization Toolkit supports DOS, OS/2, and UNIX platforms. The Internationalization Toolkit is $249.95 for a royalty-free source code license for up to 10 programmers. For more information contact *Network Dynamics, (804) 220-8771; FAX: (804) 220-5741.*

Omega Systems Ships VERSIONS

Omega Systems has begun shipping VERSIONS, a version control system for Windows. VERSIONS provides version control support for programmers by managing multiple project resources including source code, documentation, or other files. VERSION supports varied file formats, including binary files, and doesn't limit the number or types of files which can be maintained. VERSIONS is network-compatible and supports multiple developers working on the same project, allowing storage of both temporary and permanent versions of a file.

Eschewing the approach of storing incremental changes to files, VERSIONS stores previous versions of a file in a "master project," a proprietary format that labels, maintains, and tracks files for access to both the most current, as well as any past version. VERSIONS also tracks changes to a project either on a server or local workstation through the master project. Users check files into and out of the master project as needed and VERSIONS automates the process of determining which files need to be checked in or out. VERSIONS is $99. One copy of VERSIONS is required for each workstation in a networked installation. For more information contact *Omega Systems, 5405 Alton Parkway, Suite 5A494, Irvine, CA 92714, (800) 458-5467 or (714) 253-6700; FAX: (714) 253-6712.*

EMS Professional Shareware Upgrades C/C++ Utility Library

EMS Professional Shareware has upgraded its C/C++ Utility Library on CD-ROM. The library has over 1000 public domain and shareware products for programmers using C/C++, Microsoft C, and Turbo C. The products are compressed on 46 1.44 Mb diskettes or one CD-ROM. All products in the library, and 150 commercial products, are described in an indexed database which accompanies the library. When a programmer needs to locate a particular type of C/C++ product, he or she can find it by vendor, name, type, release date, or free text search across descriptions. The C/C++ Utility Library contains a variety of files, including: Array, Binary Tree, Communication, Compression, Database, Debugger, Editor, Graphics, Linked List, Memory Management, MS Windows, MS Windows NT, Paradox Engine, Program Generator, Reference, Spreadsheet, String, TSR/ISR, Virus, and other types.

The C/C++ Utility library is $59.50 on CD-ROM or $149 for the diskette versions. A subset of the C/C++ library containing 406 files for C++ only is available on 20 diskettes for $59.50. All products come with a 30-day, money-back guarantee. For more information contact *EMS Professional Shareware, 4505 Buckhurst Ct., Olney, MD 20832, (301) 924-3594; FAX: (301) 963-2708; e-mail:* `eengelmann@worldbank.org`.

Cadre Technologies Introduces Ensemble Viewer

Cadre Technologies Inc. has released Ensemble Viewer, an interactive 2-D and 3-D graphical tool for visualizing C programs.

Ensemble Viewer supports browsing of program flow, data structure, and physical file structures. Ensemble Viewer provides interactive views of key program aspects by displaying program information and test results that are stored in the Ensemble database. Ensemble Viewer lets the user interact with the software design, code, and files by viewing a graphical representation of the actual program structures. This interaction lets a user understand the program or see the impact of program changes without having to read through the source code. Ensemble Viewer is available for Sun SPARCstations and the company plans called for a release on HP9000 and IBM RS/6000 during the first quarter of 1994. Prices for Ensemble Viewer start at $2,400 depending on configuration. For more information contact *Cadre Technologies Inc., 222 Richmond St., Providence, RI 02903, (401) 351-5950; FAX: (401) 351-7380.*

TerraLogics Upgrades Mapping Software Toolkit

TerraLogics, Inc. has upgraded TerraView, its geographic mapping software development kit. TerraView v4.0, lets developers embed geographic maps directly into the source code of Windows applications developed with Microsoft's Visual C++ and C/C++ v7, Borland's C++ v3.1, Gupta's SQL Windows, and Powersoft's PowerBuilder.

Features of TerraView v4.0 include: raster data support, which lets developers superimpose TerraView data maps over aerial photographs or satellite images; style sheets, which are used to customize map displays; dynamic renditioning, which supports style changes for a single use of a map; and faster updating of mobile symbols for real-time tracking and display applications. TerraView v4.0 lets map users access data from many database managers, including Gupta SQLBase, dBASE, and Oracles, as well as Defense Mapping Agency's Digital Chart of the World and the Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) data.

TerraView v4.0 is available for MS-DOS and Windows, Apple Macintosh, and UNIX systems from SUN, HP, and IBM. For more information contact *TerraLogics, Inc., 600 Suffolk St., Lowell, MA 01854, (508) 656-9900; FAX: (508) 656-9999.*

PractiSys Releases STORC GOLD v2.0

PractiSys has released v2.0 of STORC GOLD, its Windows form conversion tool.

Computer Applications Specialists Introduces ProMet

Computer Applications Specialists has introduced ProMet, a C/C++ metrics utility. ProMet measures program size, number of comments and comment density, McCabe's and other complexity measurers, level of nesting, number of program jumps, and number of literals. These measures provide quantitative data for estimation of effort and conformance to programming style guidelines.

In addition to calculation of metrics for each function and each module, ProMet provides program summary data and a "Top Ten" report that highlights the ten functions that have the highest metric scores. The Top Ten functions are presented both in a file list and as a graph to highlight the code sections that have the highest likelihood of having errors. The Top Ten list lets testing and review resources focus on code areas that are the most complex and may suggest the need for additional oversight.

ProMet is $99 and comes with a manual that provides a background on software metrics and their use. For more information contact *Computer Applications Specialists, 9948 Hibert St., Suite 103, San Diego, CA 92131, (619) 695-2600; FAX: (619) 695-0794.*

STORC GOLD v2.0 lets Microsoft Visual C++ developers directly import Visual Basic .FRM files into C++ projects, reusing both form design and VBX controls.

STORC GOLD v2.0 is $45.93 per copy per single user. Developers can download a fully-functional evaluation copy from CompuServe (GO WINSDK or GO MSBASIC), or can obtain a copy from PractiSys for $3. For more information contact *PractiSys, 4767 Via Bensa, Agoura, CA 91301, (818) 706-8877.*

Digital Information Systems Corporation Ports PVCS to Alpha AXP

Digital Information Systems Corporation and Digital Equipment Corporation have ported Intersolv's PVCS Version Manager v5 and PVCS Configuration Builder v5 products to Digital's Alpha AXP. Under the terms of the agreement, DISC is porting, distributing, and providing technical support for PVCS products on operating systems not supported by Intersolv. DISC has completed ports to OpenVMS, VAX/VMS, OSF/1, and several UNIX-based platforms.

Features of PVCS Version Manager v5 include: SQL support facilities, expanded file support, user-defined delta generation, and internationalization capabilities. Features of PVCS Configuration Builder v5 include: run-time diagnostics, build techniques, directives, and build script compilation capabilities.

The price for PVCS Version Manager v5 starts at $599 for a 1-4 user license and Configuration Builder starts at $399. For more information contact *Digital Information Systems Corporation, 11070 White Rock Rd., Rancho Cordova, CA 95670, (800) 366-3472 or (916) 635-7300; FAX: (916) 635-6549.*

Odyssey Development Releases ISYS Search Engine

Odyssey Development, Inc., has released the ISYS Developers' Toolkit, which includes Odyssey's ISYS text retrieval software. Developers and OEMs can integrate the ISYS text retrieval engine into applications for CD-ROM authoring, electronic publishing, or document and image management. ISYS can access textual information stored in word processor and other files. ISYS can read 28 word processor formats, as well as some spreadsheet and database files. Documents to be searched remain in their native formats. The Developers' Toolkit also lets OEMs develop External Access Modules. ISYS can then access and index "foreign" data sources, such at text stored in a relational database.

The ISYS engine is available for Microsoft Windows and MS-DOS. The ISYS engine can be called from many major languages. Sample code is provided for C, Pascal, and Visual Basic. For more information contact *Odyssey Development, Inc., 650 S. Cherry St., #220, Denver, CO 80222, (303) 394-0091: FAX: (303) 394-0096.*

SLR Systems Upgrades OPTLINK

SLR Systems Inc. has upgraded OPTLINK for Windows. OPTLINK v5.0 for Windows lets developers generate compressed executables (.EXE) and Dynamic Link Libraries (.DLL). According to the company, OPTLINK v5.0 for Windows can reduce file size by 50 percent. Compressed EXEs and DDLs generated by OPTLINK become self-loading and decompress automatically as segments are demanded.

OPTLINK v5.0 supports Borland, Microsoft, and Symantec C++ compilers. Debugging support is included for Borland's Turbo Debugger and Microsoft's CodeView. As a DOS-hosted linker, OPTLINK is distributed in two forms, real mode and protected mode (DPMI).

OPTLINK v5.0 for Windows is $350. Registered owners of v4.0 will receive the v5.0 update free, while other previous owners can purchase the update for $165. For more information contact *SLR Systems, Inc., 1622 N. Main St., Butler, PA 16001, (412) 282-0864; FAX: (412) 282-7965; BBS: (412) 282-2799.*

Segue Releases QA Partner for NT and OS/2

Segue Software has released its QA Partner cross-platform GUI test tool for IBM's OS/2 and Microsoft NT. Using QA Partner, developers can test applications on either of these platforms, and the test scripts will be portable across the other platforms QA Partner supports, including Windows, Macintosh, VMS, and Motif.

QA Partner for both IBM OS/2 and Microsoft NT is $1,495. For more information contact *Segue Software, Inc. 1320 Centre St., Newton Centre, MA 02159, (617) 969-3771 :FAX: (617) 969-4326.*

Intel Ships Plug and Play Kits

Intel Corporation has begun shipping three Plug and Play Development kits. The kits are designed to help developers in making PCs easier to configure. The Plug and Play Kits contain the software to perform the automatic configuration of new Plug and Play cards and Plug and Play-ready systems.

The first kit, the "Plug and Play Kit for MS-DOS and Windows," includes a DOS driver, interface libraries, a configuration utility, a VHDL description for an ASIC implementation, and reference manuals. The second kit, the "Plug and Play BIOS Enhancements Kit," contains BIOS software that detects and configures PCI and Plug and Play ISA add-in cards. Software is available in source code form. The third kit, "The Plug and Play ISA Hardware Demo Kit," contains a functional audio Plug and Play ISA demo card and Windows v3.1 Virtual Device Drivers. The kit also includes diagnostics, board schematic files, and speakers. Bundled with this kit is the "Plug and Play Kit for MS DOS and Windows."

The Plug and Play ISA Hardware Demo Kit is $895. For more information contact *Intel Literature Packet #F8P01, P.O. Box 7641, Mt. Prospect, IL 60056, (800) 548-4725.*

FREE INFORMATION

The C Users Journal™

InstantInfo™
Response
Service

To receive free product information from the companies listed on this page, simply follow these steps:

1) Call 1-800-234-0141 from any phone.

2) Follow the voice prompts; be sure to have the product document number and your FAX number handy.

3) That's it! The information you've requested is FAXed to you immediately.

It's simple, easy and FREE.

Don't miss the additional information available about *The C Users Journal*. You can receive information about books, back issues, code availability, and much more.

Thank you for using *The C Users Journal* InstantInfo Response Service!

Advertiser	Page	Document
Burton Systems Software	31	1186
C Associates	140	1156
Cobalt Blue, Inc.	37	1157
Courseware Applications	143	1187
DBx, Inc.	54	1195
DC Micro Development	138	1151
DMARZ Diversified Sciences Co.	139	1194
EliaShim Microcomputers, Inc.	53	1159
Embedded System Products, Inc.	127	1152
Emerging Technology	113	1198
Greenleaf Software, Inc.	CII	1153
Ted Gruber Software	18	1163
Intelligent Solutions, Inc.	141	1189
Intertech, Inc.	129	1192
InTrepid Technology	123	1154
Just Logic Technologies	99	1185
KADAK Products, Ltd.	43	1188
Micro-Digital, Inc.	114	1160
Network Dynamics	139	1196
Paladin Software	100	1197
Spider Software	143	1193
Software Blacksmiths	103	1162
Voice Information Systems, Inc.	141	1165
Windbase Software	89	1191

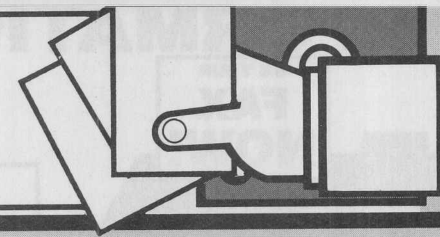
Magazine Services	Document
CUJ Subscription Information	1167
Code Disk Subscription	1168
Code Availability	1169
Back Issues	1170
CUJ Author Guidelines	1171
On-Line Index to *CUJ*	1172
C Users Group Software Library	1173
Windows/DOS Developer's Journal Subscription Information	1174
Mailing List Information	1175

Book Information	Document
C++ Programming Guidelines (Plum & Saks)	1176
C Programming Guidelines, 2nd Ed. (Plum)	1177
Illustrated C (Zolman)	1178
MS-DOS System Programming, 2nd Ed. (Ward)	1179
mC/OS The Real Time Kernel (Labrosse)	1180
Windows Custom Controls (Smith & Ward)	1181
Object-Oriented Software Engineering (Halladay/Wiebel)	1182
The Standard C Library (Plauger)	1183
The C Users Journal Book Catalog	1184

Free Product Information — 24 hours a day!

1-800-234-0141

Call for Papers



The C Users Journal is seeking articles on the topics below. If you have an idea for a related story, or experience that would qualify you especially to write on one of these topics, please write:

P.J. Plauger, Senior Editor
The C Users Journal
1601 W. 23rd St., Suite 200
Lawrence, KS 66046-2700
(913) 841-1631

The C Users Journal is written *by* practicing programmers *for* practicing programmers. We insist on practical treatments of real programming problems, or on tutorials that make theory or complex issues more accessible to practicing programmers. In place of product reviews, we publish user reports that show — with insight backed by experience — how to use commercial products that aid the program developer. Our emphasis is on C and C++, or on tools used in conjunction with these languages.

We pay at rates that are competitive with other national technical journals. We believe that our editorial assistance is better than most. You don't have to be a professional writer to meet our acceptance criteria, but you must have something to say. Ask for a copy of our Author Guidelines.

A proposal consists of a brief abstract and outline, preferably totalling no more than one page, and a brief resume of your qualifications. You *must* submit your manuscript on an MS-DOS diskette, or via email (`marc@rdpub.com`). Files must be in raw ASCII format, flush left, with one empty line between paragraphs.

Themes

Software Tools

Proposals Due 02/07/94
Drafts Due 03/21/94

Suggested topics: portable "shells" and toolkits; small programs that serve as useful building blocks for applications; small programs that aid program development or analysis; reusable tools in a windowing environment; C/C++ libraries that make tools more uniform.

Overworked topics (require fresh perspective): heap trace analyzers, "make" utilities.

Graphics

Proposals Due 03/07/94
Drafts Due 04/18/94

Suggested topics: writing C or C++ code that ports easily among the major GUI environments; useful graphics classes and libraries; algorithms for drawing, shading, windowing, scaling, etc. that are efficient and/or elegant; techniques for visualizing data; manipulating gray-scale and color images.

Overworked topics (require fresh perspective): graphics object classes, graphic file reformatters.

Windows Programming

Proposals due 04/08/94
Drafts due 05/20/94

Suggested topics: C++ class libraries and other scaffolding that simplifies programming under Windows; debugging under Windows; writing C/C++ code that is portable across Windows/Mac/X; useful small Windows utilities in C/C++; using C/C++ to coordinate (script) running other programs; simplifying input under Windows.

Overworked topics (need fresh perspective): simulating stdout or stderr in windows.

Also

Features

If you have an idea for an article that you think might help other C or C++ programmers, you don't have to wait for a more-or-less appropriate theme to roll around. Send it in anytime. Uses for C and C++ are growing too rapidly to count, particularly in a mere twelve categories. So use your imagination, and we may use your words.

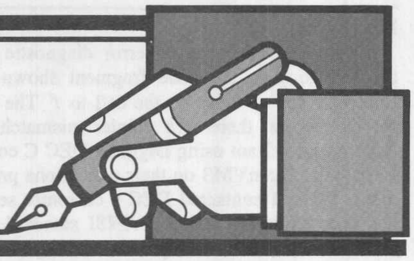
User Reports

If you are willing to share your experiences with a certain product, send us a user report. A user report is not a product review. It is a more anecdotal description written by someone who uses products to get useful work done. Instead of letting vendors trumpet their own products, we want you, the reader, to do it for them — or say why the trumpets should be muted.

Book Reports

If you are willing to share your opinion about a book you have read to improve your understanding of software development, send us a book report. Give your fellow programmers a brief synopsis: an overall evaluation of the book, listing the strong and weak points. Include suggestions for improvement. For more information, ask for the Author Guidelines.

We Have Mail



Letters to the editor may be sent via email to cujed@rdpub.com, *or via the postal service to Letters to the Editor,* The C Users Journal, *1601 W. 23rd St., Ste. 200, Lawrence, KS 66046-2700.*

Dear Mr. Plauger:

There are a number of aspects of the current state of the art of software engineering that I find less than satisfactory. They are

1) Bug-infested tools
2) The dearth of productive engineering tools
3) The programming languages themselves.

First of all, I have used Lattice C, Turbo C, and Microsoft and Borland C/C++ compilers. Our group chose the latter two for their third-party and Windows support. First I used Lattice C 3.1. It didn't do `float`s but `double`s seemed to work OK. Next I used Microsoft v5.0. It optimized code out of existence. Because of that we switched to Turbo C/C++. It refused to do assignments of floating point (`float` or `double`) literals in the range between 0 and 1!

This problem only occurred when linking together 20-odd modules. In a three-module test program all worked fine. Due to project deadline pressure I was never able to whack away at the 20-odd modules to the point where the problem went away in order to determine its cause. I worked around it. This problem was also present in Borland C/C++ 3.0, but does not occur in version 3.1 with identical source code. I have seen two instances where Borland C/C++ 3.1 handled the following snippet where the function returns the value 1 by not taking the `if`:

```
if ( func() )  // returns 1
  do_something(); // never executed
```

Changing this to the following worked, however:

```
status = func();
if ( status )
  do_something()
```

My first gripe about the state of the art is that compiler vendors seem to concentrate on features like IDEs, 32-bit versions (64-bit next, no doubt), Windows support, etc., while basic functionality is not solid. Floating point seems especially difficult for these people. (You'd think that after ten years of writing C compilers...) I really don't know if Borland C/C++ v3.1 has floating point problems; I just haven't seen any problems so far. Now if Borland and Microsoft are the least-buggy products on the market, I'd hate to see the others. I would love to be able to trust the compiler, but that seems to be wishful thinking. At least we have debuggers to go roto-rooting in the generated assembly code.

More and more vendors are charging for phone support. Now I get to *pay them* for reporting bugs in their products. Borland actually told me to call their 900 number to discuss a bug! No thanks! Along with the bug situation, I wish compiler error and warning messages were more accurate. In many cases I have to ask myself, "Now what does it *really* mean?" I use PC-LINT religiously. To the compiler vendor's credit, error and warning messages have been getting better in recent years.

Now lets add C++ on top of this whole mess. I enjoyed your article, "Programming Language Guessing Games" in *Dr. Dobb's* (October 1993). I agree of course with your suggestion to "pick a subset of the [C++] language that minimizes surprises, learn it well, and don't stray from it." The problem is that the compiler vendor chooses to support everything that looks like it will make it through the ANSI committee. If they can't get some of these simple things solid (like the function return value example above) how can I trust them to do some of the complicated things you have described for C++? Even if I *do* restrict myself to a subset of the language, it could be that the other features induce bugs in the parts that I am using. The bottom line is that the majority of our time is spent on maintenance. Compiler bugs cost us. Secondly, the support tools available do not help me with software engineering (as opposed to hacking which I define as, "code it first without thought of design, document it later") as I would like. Diagrams are a neat idea, but then we have to translate the diagram into code by hand and translation is where errors creep in. Management might go for the time spent on diagramming if automatic code generators were available. Code generators for Windows screens and other user interfaces are generally available, but I haven't seen any for other parts of a program. A framework generator would be nice. Hardware engineers have schematic capture and printed-circuit-board layout tools including auto routers, but as software engineers, we do analogous things by hand. Also, I've yet to see a decent cross-reference generator after evaluating several. The ones with usable output are way too slow. I use GNU CTAGS, but wish it did more. I know of no general purpose, highly configurable cross-reference generator. We have written our own programs and editor macros to insert comment blocks for functions and modules and for extracting those into a Word document, but so much more could be done. I am beginning to write add-on tools for Codewright, a very extensible Windows programmer's editor. Thirdly, despite some ugly features of C, I like it a lot (more than Pascal, Modula-3, Eiffel, etc.). For example, C overloads the `static` and `void` keywords, allows functions to return pointers to automatic variables, and various other gotchas mentioned in Andrew Koenig's *C Traps and Pitfalls.* (Being able to execute an array of opcodes is a feature?) But for the sadist, C++ is a real treat. Now we have not two but three meanings of `static` and not two but four meanings of `void`!

C and C++ violate many of the accepted guidelines of language design. Many things can be done several different ways, much of it behind the scenes. I shudder whenever I read one of your articles concerning C++, your latest in *The C User's Journal* on the Standard C++ library included (P.J. Plauger, "Standard C: Developing the Standard C++ Library," *CUJ,* October 1993). I know that I cannot avoid learning C++, but hopefully it will be replaced soon with something simpler. We need new paradigms and metaphors to handle advanced concepts. Languages will *have* to become more complicated, but they should be as simple as possible. I like the approach taken by Meyer in Eiffel of including an extensive set of libraries. The less I have to write myself, the more productive I am. Hopefully, libraries supplied with compilers are well thought-out and bug-free. I wish Borland C/C++ came with the library support that Eiffel or NextStep Objective-C does. A collection of third-party classes or libraries does not have the consistency that a single-sourced library does. I have only touched the surface of some current problems in the software industry. What I would like to know is:

1) Which in your experience are the least-buggy C/C++ compilers?
2) Do you know of a diagrammer w/code generator? What other engineering tools have you found to be helpful?
3) Do you know of any cross-reference generator that outputs a list of identifiers including the module name, line number, *and function* (if any) they were found in, *and that is fast?*
4) What do you think of Modula-3, Eiffel, and IBM's Object REXX? Thank you in advance for your help. Thanks for your excellent articles. Please keep them coming.

BRUCEDICKEY@VAX.MICRON.COM
Bruce Dickey
Micron Semiconductor, Inc.
2805 E. Columbia Rd., MS 892
Boise, ID 83706

Whew! You raise a whole slew of issues. I agree with you almost across the board, except that I am a bit more sympathetic to the plight of all those compiler vendors out there scrabbling for market share in a turbulent industry. I guess that comes from selling compilers myself for ten years. Growing complexity seems always to offset gains in our ability to manage software development and reduce shipped bugs.

I don't know how to answer any of your questions at all well, but I invite other readers to chip in. My opinion of Modula-3 and Eiffel, for what it's worth, is fairly simple. Both offer interesting combinations of features, but neither has quite pulled off the synergy of C or C++. I don't know enough about REXX to comment. — pjp

Dear Editor,

My compiler issues an error diagnostic on the call to *g* in the code fragment shown in Listing 1, but no error on the call to *f* The error claims that there is a pointer mismatch in the argument. I am using Digital's DEC C compiler under OpenVMS on their new Alpha processor. When I contacted DEC's customer service, they explained that the ANSI standard allows conversion from a pointer to a qualified type to a pointer to a non-qualified type, but does not allow 'ignoring' the qualifier for a pointer to a pointer to a type. Their argument seemed somewhat niggling to me, so I wanted to appeal to a higher authority. How do you think a compiler should handle this code (shown in Listing 1)? Sincerely,

Dick Hile
T and B Computing, Inc.
24 Frank Lloyd Wright Dr.
P.O. Box 302 - Lobby A
Ann Arbor, Michigan 48106-0302

DEC is correct. The distinction may appear niggling to you, but we meant to do it that way when we wrote the C Standard. — pjp

Dear Mr. Plauger,

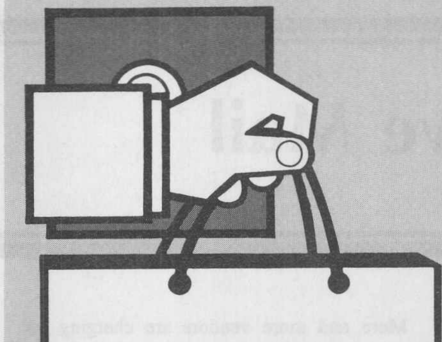
I would like to add my two cents' worth to Mr. Mike Musielski's comments (*CUJ*, October 1993) on the nature of C as a language. ("Is C a language?" was his opening question.) The short answer to that question is, no, C is not a language. Neither is any programming language. The programming-as-writing analogy is interesting, but like most analogies it is partly true and partly dangerous.

A programming language is really a notation system: defined narrowly, conceived as a formal means of expression, and limited in its range of expressiveness, at least when compared with natural languages. No programming language is used as an end in itself (except of course by participants in Obfuscated C contests), whereas a natural language is used that way all the time by artists whose only goal it is to explore the language's poetic possibilities. This is the main reason why programs, no matter how short, cannot be compared to short stories or other forms of fiction.

Nevertheless, there is a basis for the analogy. Like natural languages, programming languages

Listing 1 *Creates "pointer mismatch" error message*

```
char x;
char *xp = &x;
char **xpp = &xp;
void f(const char *cp)
    {}
void g(const char **cpp)
    {}
void a(void)
    {
/* Call to 'g' gets pointer mismatch error */
    f(xp);
    g(xpp);
    }

/* End of File */
```



Programmer's Market

do evolve and adapt themselves to new situations and conditions. And as they do, new vocabulary creeps in, functions begin to overlap, and things begin to get — well, messy. Even standards cannot clear up all ambiguities: there will always be more than one way to skin a cat. You can say "pass away" or "kick the bucket," just as you can use `strtol` or `atol`. Both elements in each pair approximate, but do not exactly map, the same idea. How are you to recognize when it is appropriate to use one and not the other? This is what Mr. Musielski wants to know.

There are some useful texts out there. I suggest Mr. Musielski look at (again, if not for the first time) *The C Programming Language,* by Kernighan and Ritchie. Another book I have found useful on occasion is *C Lab Notes,* by Flanders and Holmes. This book has a nice feature in that each chapter has at its head a list of the tasks that are to be explored inside ("forward and reverse scrolling," "sending a message to another node," etc.). And, not least, *The C Users Journal* is itself very instructive in matters of language use. None of these texts is consciously "literary," but all take the implicit stance that a programming language is an idiom to be mastered. Mastering the language (your "material") is the goal of literary writing as well.

I think what might be very beneficial to Mr. Musielski (and others, myself included) would be a kind of reverse dictionary: a list of common tasks along with the range of functions, procedures, tools, etc. that could be used to fulfill each task's requirement. Such a book could not possibly be exhaustive and the organizational problems would be daunting, but a good text like this might be useful enough to be a starting point. Of course, as writers learn from writing, programmers learn best from programming. There is still no effective substitute for trial and error--many trials, many errors.

Sincerely,

Michael Nichols
1725 York Avenue
New York, New York 10128

Thanks for your insightful comments. — pjp

Editor:

I found Robert Watson's "DMA Controller Programming, in C" (*CUJ,* November 1993) interesting, particularly of course the protected-mode details, but found his conclusion, "the technique is actually very easy to use" laughable, considering what he had just painstakingly documented. "Virtually impossible" is more like it. I agree with his further conclusion: that DMA is increasingly obsolete, since fast CPUs deal with dedicated card memory blocks more expeditiously (and of course the implication that such memory is relatively cheap in modern times — DMA was originally a cost as well as speed feature).

I also think along the way he erroneously minimized the difficulties involved in getting hold of a DMA buffer in real mode ("in real mode, generating a DMA buffer is relatively easy"). I hope I'm missing something, but in my source where I tried to accomplish this there are three or four failed attempts commented-out, and I'm not at all happy with my current effort, shown in Listing 2.

If anybody knows how to do this rationally, stop me before I code again! The crude strategy here is to keep getting buffers, and if they're no good — won't do DMA because they cross a physical boundary — retain the offending part of the buffer and keep trying; and then when we get a good one, free all the chunks accumulated along the way. This approach relies on totally unreliable assumptions about memory allocation, and really comes down to a "keep trying until you give up" approach.

Operating systems in 80x86 land get to own low memory, where it is relatively easy to set-up a good DMA buffer. Programs, on the other hand, can be loaded at any address, and can't make any such arrangements except, as far as I can figure out, by using awful things like the example.

And incidentally, who owns the VDS (Virtual DMA Services) interface mentioned in the article? I have a vague idea how one goes about getting in touch with DPMI; is VDS one of these things that comes with DOS extenders and/or Windows or what?

j.g. owen
Software engineer
31 Darby Drive
South Huntington, NY 11746
cis 71121,625

Listing 2 *Attempts to allocate a real-mode DMA buffer*

```
#define BYTE char
typedef unsigned int WORD;
typedef unsigned long BIG;

#define JUNKCHUNK (128)
/* how we will search for physical
boundaries. (Must be >= sizeof(JUNK))
*/

/* produce a big physical address. This
is "large" mode code; " FP_SEG" etc.
are
Turbo C macros which extract the two
parts of an 80x86-style segment-offset
pointer. */

#define PHYSICAL(x) ((BIG)((((BIG)
    (FP_SEG(x)))<<4)+((BIG)FP_OFF(x))))

typedef struct JK
  struct JK *next;
} JUNK;

_f void *mustallocdma(WORD size) {
  BYTE *a;
  JUNK root, *next, *p;
  BIG leftover;
  WORD junksize;
  root.next=NULL;
  next=&root;

  while(1) {
    a=mustalloc(size);
    /* mustalloc==malloc,
    but aborts if failure;
    the function exits this
    way or via the break below
    at success.*/
```

To the Editor:

Concerning the letter from Lawrence H. Hardy in the 11.12 issue of *CUJ*, page 136, asking for information about PCX graphics:

And I thought *my* memory was going... Actually, this might instead be seen as an illustration of the need for a *CUJ* index — depending on one's perspective of course. At any rate, whilst fumbling through a stack of old *Journals* seeking edification on a particular coding problem, I came across Vol. 9, No. 8 (August, 1991). Emblazoned across the cover was "PCX GRAPHICS DOCUMENTED!" And sure enough, there on page 89 was a decent discussion of the topic by one Ian Ashdown, complete with bibliography.

I would also like to join Ian Somerton (p. 127) in expressing concern, if not alarm, at the exponential increase in C++ coverage of late. Perhaps someone on your staff misread it as C**?

Sincerely,

Scott Swanson
Box 75
Pendroy MT 59467

I am notorious within R&D for my instant amnesia, once an issue goes out the door. You're right that an index to CUJ is indispensable, and the folks back in Kansas have anticipated your wish. As for C++ coverage, that happens to be an area of intense interest in our community at the moment. We haven't forgotten about C by any means, but the mix what we publish is strongly influenced by the mix of what's proposed to us in the way of articles. — pjp

Listing 2 *continued*

```
        if (
        (leftover=(PHYSICAL(a) & 0xffff)) +
        ((BIG) size)
        >= 0x10000) {
          /* it's no good. */
          if (
          (junksize = 0x10000-leftover)
          < JUNKCHUNK)
          junksize=JUNKCHUNK;
          /* avoid endless
          teeny-tiny manipulations. */

            free(a);
            next->next=mustalloc(junksize);
            next=next->next;
          }
          else
          break; /* success! */
      }
      /* free debris. */
      next=root.next;
      while(next)
        p=next;
        next=next->next;
        free(p);
        }
        return a;
      }

      /* End of File */
```

C, C++ and BASIC programmers, now you get much more than xBase compatible DBMS power.

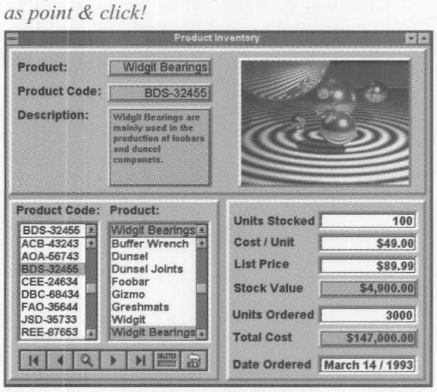
Thousands of programmers have already discovered how to get dBASE, FoxPro and Clipper compatibility from their favorite language and hardware platform. For example, one customer has C programs running on PC and Sun workstations sharing data with concurrently running FoxPro for Windows applications. You see, CodeBase technology is simply the best way to add multi-user xBase compatible DBMS power to C, C++, or BASIC.

You still get high speed & small size

CodeBase users really appreciate our small executable size. Unlike SQL engines which are a Meg or so in size, CodeBase 5.1 EXE's can be as small as 45K! You'll also like the speed–with our Intelligent Queries you get the execution speed of C plus stunning query performance from our smart use of available index information.

Introducing CodeControls

Now formatted data entry in Windows is as easy as point & click!



Introducing the new CodeControls, a unique set of data-aware custom controls. Now simply drop them into your Windows applications via your favorite visual interface builder.

NEW–You get formatted data entry

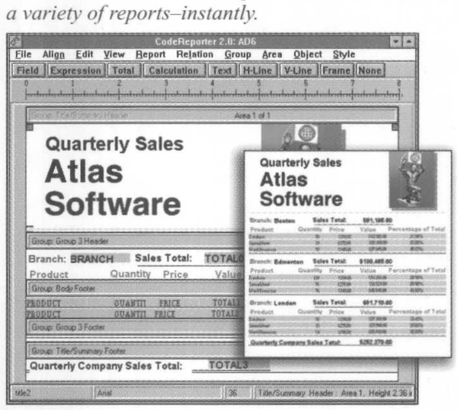
Experienced Windows programmers know **formatted** data entry is difficult to program under Windows. But with our new ***CodeControls***, you can simply 'Point & Click' to design data entry windows for date, numeric, and character information–formatted just the way you want it.

NEW–Data-aware controls

Our custom controls are ***data-aware,*** so now you can easily build a scrolling list box that's tied to a data file, or look up matching combo box entries–even as the user types.

Introducing CodeReporter 2.0

Now use the new Instant Report Wizard to create a variety of reports–instantly.



Introducing the new CodeReporter 2.0, our interactive xBase report writer. We designed it with developers in mind, and end-users will love it.

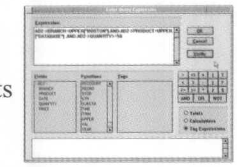
NEW–You get instant reports

Use our new Instant Report Wizard to quickly create a wide variety of reports–in an instant, then easily refine them as necessary, or let your end users build their own special reports!

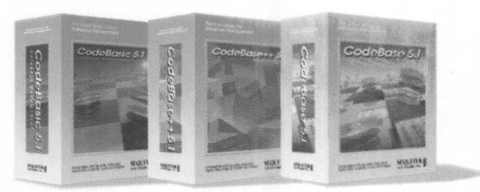
NEW–You get drag & drop

We've added drag & drop capabilities to ***CodeReporter,*** so regardless of whether you want data, totals, or text, simply drop a report object onto your layout screen.

NEW–You get interactive queries, sorts, & relations



Use CodeReporter to visually design reports easier than ever. For example, you can quickly build query and sort expressions using our calculator-style expression builder. In addition, you can easily relate data files together using our graphical relation builder.



"There's never been a better time to buy into CodeBase technology. You get complete xBase compatibility, full DBMS power, plus an interactive report writer and a set of unique data-aware custom controls for Windows."
-Ken Sawyer, President, Sequiter Software

Buy One, Get Two FREE.

Now when you buy any one of our xBase library products: ***CodeBasic, CodeBase++,*** or ***CodeBase*** (for the language of your choice), you'll get both the new ***CodeReporter 2.0*** AND the new ***CodeControls*** absolutely FREE–for a limited time only.

To Order Now Call 403-437-2410

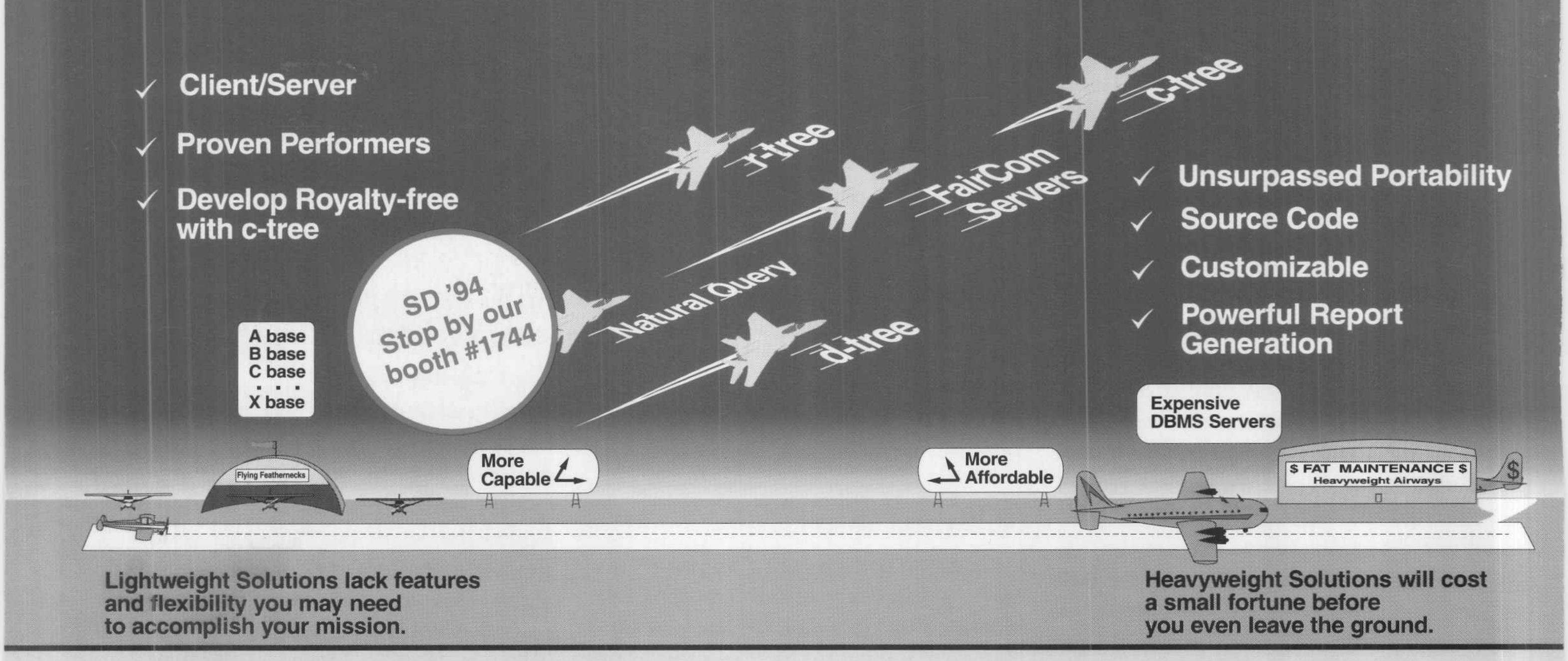
Unconditional 90-Day Money-Back Guarantee

SEQUITER SOFTWARE INC.
FAX 403•436•2999
UK Tel. +44-81-317-4321
France +33.20.24.20.14
P.O. Box 575 Newmarket NH 03857-0575

✧ Request 257 on Reader Service Card ✧

DOS · SCO · SUNSOFT · HP9000 · RS6000 · 88OPEN · BANYAN · MAC · QNX · AT&T · SUN

FAST, PORTABLE C DEVELOPMENT TOOLS



FairCom® Offers A Full Line Of High-Performance Servers & Development Tools At Reasonable Prices.

FairCom Servers®

SQL & non-SQL

These multi-threaded database servers offer a seldom-found solution for developers who demand control. While one may mandate SQL access, another's real-time demands may not tolerate the overhead associated with SQL. Our unique servers offer the full range of data accessibility: low-level speed; convenient ISAM-level; compatible SQL-level. Complete **data integrity** is achieved with multi-user transaction processing. Recovery of all committed transactions after a failure is fully automatic. The C developers 'CLIENT/SERVER' solution: **DOS nodes** to **UNIX servers**; full commit and rollback; roll forward; precise control over your data and/or data base model; large files (4GB); **complete client source code.** On-line data backups with maximum data availability and protection. These servers are designed to achieve maximum power and flexibility without sacrificing control.

r-tree®

Report Generator

r-tree report generator provides complex, multi-line reports by virtually handling every aspect of report generation. Your only programming requirement is to call the r-tree report function, which reads c-tree data files, performs calculations, monitors control breaks and accumulators and produces a formatted report.

c-tree Plus®

High Performance Data Management

Based on the most advanced B+ Tree routines available today, c-tree Plus gives you unprecedented control over your file management needs. With unparalleled sophistication, c-tree Plus has established itself as the premier choice for commercial development. Use the low-level routines or take advantage of the high-level ISAM routines for high speed random or sequential access. c-tree Plus is distributed in **complete C source code** and is known for its portability and **royalty-free** licensing policy. Whether for single-user, multi-user or client-side application development, c-tree Plus delivers. Transaction processing is included in c-tree Plus as well as features like: fixed/variable length records and keys; dynamic space reclamation; high speed hashed data and index caching (and savepoints, abort, and rollback); full ISAM functionality; and batch operations. All functions are fully ANSI prototyped. Call for a complete list of features.

Natural Query™

Natural Language Tool

Produces ad hoc reports quickly and easily from English sentences. It is the first **low-cost,** natural language tool designed for developers and a broad range of users. The QBE option has **easy-to-use,** pick and choose menus, making report specifications a snap. Available in VAR or end-user versions.

✧ Request 128 on Reader Service Card ✧

d-tree Toolbox®

Application Development

Productivity tools with: a complete **portable screen handler**; data dictionary; code generation; easy to use data base interface; menus; help text; data validation. d-tree's dynamics allow **runtime control** of program resources (screens, files, edits, etc.) not found in any other development package. Resources can be changed in memory, and/or swapped on/off of disk at runtime. Additional productive features include: flexible data windows; field masks; user-defined and field-level edits and **data file reformatting.** If you do application development on multiple platforms (DOS/UNIX), or you're debating 4GL versus C development, d-tree is for you.

Call today for more information:

(800) 234-8180

FAIRCOM® corporation

4006 W. Broadway . Columbia, MO 65203
(314) 445-6833 Fax (314) 445-9698

FAIRCOM EUROPE
Via Sottocorna 15/17 · ALBINO (BG) ITALY
tel. 035/773464 · FAX 035/773806